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DEFORMATION OF YULE MARBLE: PART V—EFFECTS AT 300°C

By David Griggs, Francis J. Turner, Iris Borg, and John Sosoka

Abstract

Yule marble has been deformed at 300°C, at 5000 atmospheres confining pressure, under conditions otherwise identical with those at room temperature and at 150°C (Parts I–IV). The important new effects are: apparent development of intergranular flow (recrystallization[1]) and development of textures closely resembling those of naturally deformed marble. Fabric measurements on the deformed material show trends nearly identical with those observed in specimens deformed at lower temperature (Parts III and IV). The effect of interstitial water is negligible except for lowering of strength similar to that observed at room temperature. Slow rates of deformation seem to favor recrystallization. Granite has been deformed plastically for the first time.

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Introduction

Parts I–IV of this series of papers (Griggs and Miller, 1951; Handin and Griggs, 1951; Turner and Ch'ih, 1951; Griggs *et al.*, 1951) described the physical properties and fabric changes in Yule marble deformed at room temperature and at 150°C under confining pressures of 5000 and 10,000 atmospheres (equivalent to depths of about 15 and 30 km in the earth's crust). The present paper describes similar observations at 300°C at 5000 atmospheres

[1] The term *recrystallization* as used in this paper follows Griggs' (1940, p. 1003) definition of recrystallization flow:—"deformation by molecular rearrangement through the medium of solutions, local melting, or solid diffusion; intergranular motion dominant".

confining pressure. In the absence of local heating 300°C is about the temperature to be expected at a depth of 30 km in the earth. Griggs and Sosoka did the experimental phase, Turner and Borg did the fabric studies.

Acknowledgments

The experimentation and fabric studies were both supported by grants from the Office of Naval Research, and from the Penrose Bequest of The Geological Society of America. Apparatus on loan from Harvard University and from the U. S. Geological Survey was essential. The excellent craftsmanship of Mr. Fred Banning in the Institute of Geophysics shop was indispensable. Mr. Hugh Heard performed the experiments on calcite single crystals and a few of the experiments on marble. Mr. John de Grossé prepared the excellent thin sections. The Yule marble was provided by Mrs. E. B. Knopf, out of whose inspiration this program has grown.

Experiments

Apparatus and Procedure

The apparatus and procedure have been fully described in Parts I and IV. The only difference in the work at 300°C is the method of jacketing the specimens. The solder used on the early jackets melted at 300°C. After some abortive attempts to use high-melting solder, a mechanical closure was developed which is leakproof if certain design precautions are observed [see Handin (1953) for details]. This removes one uncertainty present in former experiments—the effect of the soldering flux.

Procedure for measurements, calibrations, and reduction of data is as described in Part I. The rate of strain is the same—1.5 per cent per minute. All Yule marble specimens were cut from the same block as that used for experiments described in Parts I and IV. The temperature of the specimen was determined by calibration as in Part IV. There is a substantial temperature gradient in the test section, amounting to about 10°C in the specimen. The maximum temperature is 300°C and occurs near the middle of the specimen.

Results

Dry Yule marble.—Figure 1 shows the stress-strain curves for Yule marble dry, at 300°C, 5000 atmospheres confining pressure, for cylinders of *1*, *T*, and *d* orientation, in extension and in compression. These orientations are the same as in Parts I–IV: the axis of a *1* cylinder is normal to the foliation in the undeformed marble; that of *T* is in the foliation plane; that of *d* is at 45° to the foliation. Each curve is an average of two or more experiments. Two *1* cylinder tests and two *d* cylinder tests were discarded since the specimens in question were from 15 to 25 per cent weaker than others of the same orientation. The remaining 15 tests have an average of 2.2 per cent departure from the mean for the orientation in question as measured at 3 per cent deformation. The reproducibility is thus about the same as that of the experiments at room temperature, and much better than that at 150°C, 10,000 atmospheres confining pressure.

The stress, at 3 per cent strain, of the 300°C curves averaged 55 per cent that at room temperature. At 150°C, the stresses at 3 per cent averaged 66 per cent that at room temperature. These figures were all computed for tests at 5000 atmospheres. The effect of increasing the pressure to 10,000 atmospheres has been shown to be small at room temperature and at 150°C (Part IV, p. 1392). No experiments have been done at 300°C and 10,000 atmospheres because of strength limitations of the present apparatus.

The relative strengths for the three different orientations are markedly different from those at room temperature, but only slightly different from those at 150°C.

In Parts I and IV, it was found that differences in the stress-strain curves for the different orientations could be correlated with the stress differences to be expected from the initial fabric on the basis of a simplified treatment following Taylor's hypothesis of homogeneous deformation and assuming that deformation was dominantly twinning and translation on $\{01\bar{1}2\}$.

This method (*see* Part I, p. 860–861) was tested for its ability to correlate the relative strengths at an average shear strain of 0.1. The standard deviation of the calculated

stresses from the observed ones was 13.0 per cent, whereas the standard deviation of the observed stresses from their mean was 14.4 per cent, so that no significant correlation was obtained. Since the work on calcite single crystals (*see* below) had indicated that $\{10\bar{1}1\}$ translation was important at 300°C, a similar test for correlation was tried assuming that deformation occurred by $\{01\bar{1}2\}$ twinning and $\{10\bar{1}1\}$ translation. The standard deviation of the calculated from observed stresses was 10.7 per cent—no significant correlation. Taylor's hypothesis of homogeneous grain deformation presumes no intergranular motion. The fabric of Yule marble deformed at 300°C indicates a considerable amount of intergranular motion. This is one possible cause for the poor correlation obtained.

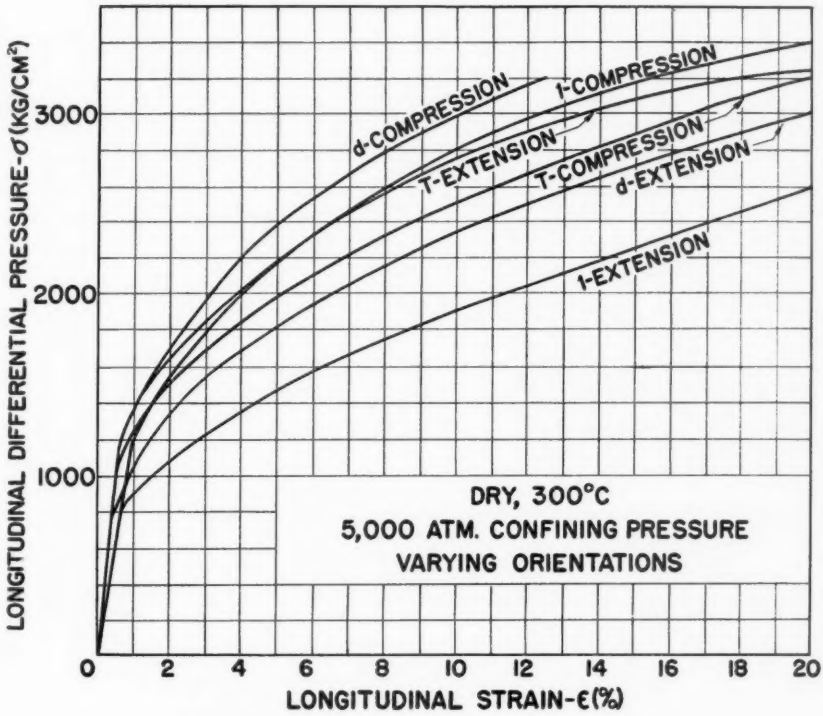

FIGURE 1.—STRESS-STRAIN CURVES OF YULE MARBLE

Wet Yule marble.—The effect of interstitial water at 300°C is similar to that reported at 150°C (Part IV). Figure 2 shows stress-strain curves for varying amounts of water for *1* cylinders in compression. One experiment with a 10% $MgCl_2$ solution is included. Comparison of these curves with the similar curves of Figure 3 of Part IV might seem to indicate that the effect of water is less at 300°C than at 150°C. Such a conclusion would seem to us unfounded since our method of determining water content is not accurate; the two sets of experiments were carried out under different confining pressure; and the method of jacketing was different (in the earlier experiments some soldering flux was always present in the fluid).

As reported in the work at 150°C, microscopic examination of marble deformed wet at 300°C showed no differences from the dry specimens that could be attributed to the presence of the

interstitial fluid. There is no evidence contrary to our previous conclusion that the main effect of water is mechanical. The amount of magnesium in the $MgCl_2$ solution was sufficient to cannot occur, the response of the specimen is definitely different from that at room temperature. Interpretation of thin sections of such specimens is difficult. Turner is undertaking an

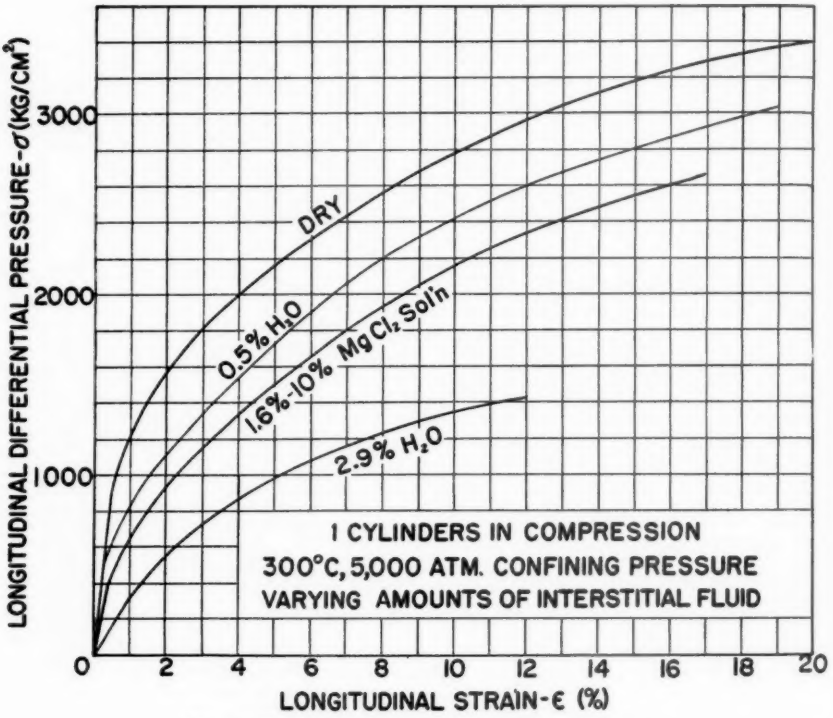

FIGURE 2.—EFFECT OF VARYING AMOUNTS OF WATER

dolomitize only 0.1 per cent of the marble if the reaction had gone to completion, so it is perhaps not surprising that this had no special effect. Attempts were made to use larger amounts of $MgCl_2$ solution, but these failed, owing to loss of cohesion of the specimen.

Single crystals of calcite.—Cylindrical specimens cut from single crystals of calcite in various orientations were deformed at 300°C, dry, at 5000 atmospheres confining pressure. When the orientation of the stress is such as to favor twinning on $\{01\bar{1}2\}$, the specimen twins in a fashion similar to that at room temperature and at 150°C, at the same critical resolved shear stress within our experimental error. When, however, the orientation is such that twinning intensive microscopic analysis of thin sections of all calcite single crystals which have been deformed at room temperature, 150°C, and 300°C. His results will be published separately. His work to date indicates strongly that translation on $\{10\bar{1}1\}$ is the dominant mechanism at 300°C.

Creep.—It was thought that a test of longer duration would accentuate intergranular motion (recrystallization). Accordingly, a *1* cylinder was tested in compression, dry, at 300°C for a 48-hour period. The stress-strain curve is shown in Figure 3. It was intended that the stress should be maintained constant at an appropriate value to produce 40 per cent deformation in 48 hours. The creep properties were

not known, however, so that it was necessary to explore with increasing stresses. As shown in Figures 4 and 5, at 1900 kg/cm², the creep rate decreased inversely with the time, indicating for 200 minutes. Only elastic flow was observed, with the possible exception of perhaps 0.2 per cent pseudoviscous flow in the last 100 minutes. The stress was then raised to 3100 kg/cm² and

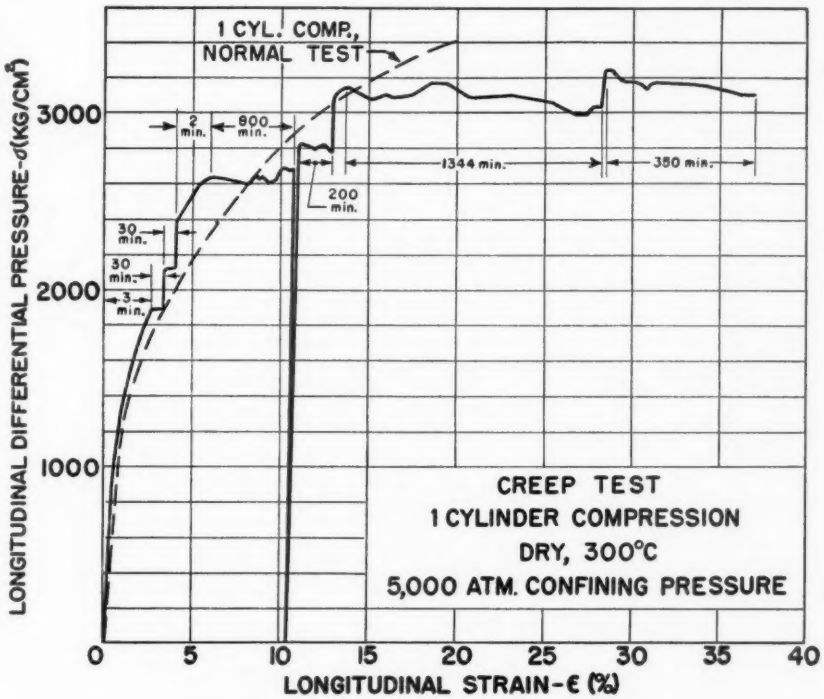

FIGURE 3.—STRESS-STRAIN CURVE OF EXPERIMENT 400

only "elastic" or recoverable flow. The same behavior was observed at 2100 kg/cm². At 2600 kg/cm², a substantial amount of "pseudoviscous" flow was apparent. The creep curve is obscure, however, because of inability to maintain the stress constant, as shown in Figure 3. After 800 minutes at approximately 2600 kg/cm², the stress was released to check the piston friction and reverse elastic or recoverable flow. Piston friction had increased an amount corresponding to 200 kg/cm² on the specimen. The applied stress therefore not only varied but is indeterminate to something like ±100 kg/cm².

When the stress was reapplied, the marble behaved elastically up to 2800 kg/cm² where the stress was again held relatively constant maintained roughly for 1344 minutes or 22.4 hours. As shown in Figure 5, about 10 per cent of nonrecoverable flow ensued. Similar behavior was observed at about 3200 kg/cm² with a greater rate of flow. The deformation may be divided into the following categories:

	Per cent
Elastic strain	2
Plastic strain at the normal rate—.015 in. min	5
Elastic flow	8
Pseudoviscous flow at nearly constant stress	22
Total	37

Thus the flow is of the type to be expected by intergranular motion or recrystallization.

It is a surprise to the writers that the applied stresses are so high for these rates of strain. It is conceivable that in these long-continued tests plastic flow in these experiments was 3 per cent, under a super-imposed compressive stress of 14,400 kg/cm². This experiment was terminated

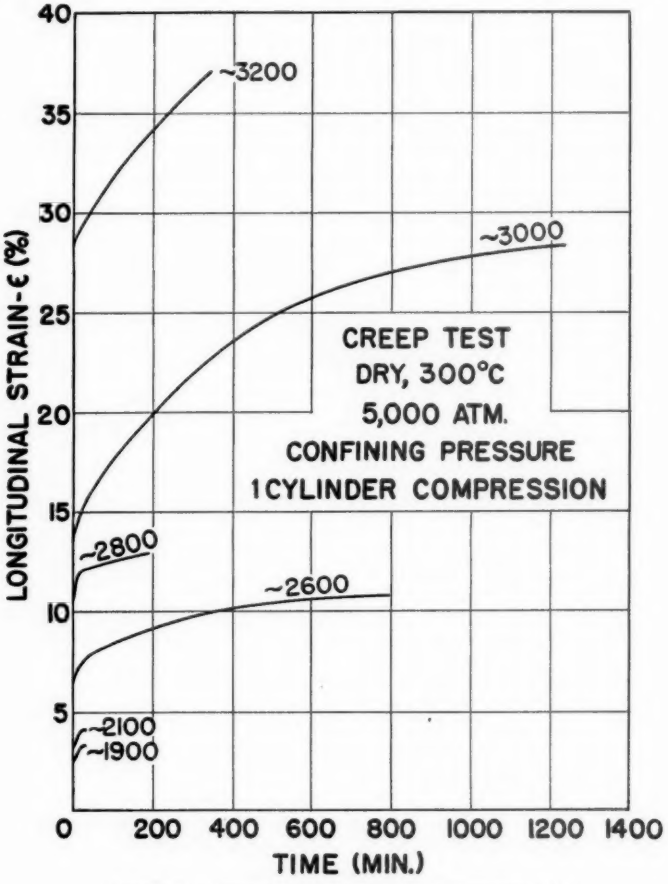

FIGURE 4.—STRAIN-TIME CURVES OF EXPERIMENT 400

the friction on the pistons rises to abnormally high values. This seems excluded, however, by the fact that a slight variation in the indicated load is promptly reflected in an appropriate change in the rate of creep. The fabric of this specimen will be described later.

Miscellaneous.—Westerly granite was deformed plastically at 300°C, dry, 500 atmospheres confining pressure. Several experiments indicate that the elastic limit under these conditions is about 10,500 kg/cm². The maximum at the onset of shearing fracture. An excellent section was prepared by de Grossé. A zone of shear is evident, marked by slightly offset grains and a small amount of shearing of the micaceous minerals. Outside the zone of shear, the predominant visible effect is distributed fracturing of the grains and undulatory extinction. The section has the general appearance of a rock deformed at moderate depths where flow and fracture occur concomitantly. This and the nature of the stress-strain curves sug-

gest that slightly higher temperature or pressure will permit large flow without fracture. Some of our experiments in which the differential stress was released prior to the onset of shearing fracture exhibit only evidence of uniform flow. Doubtless there is some microscopic fracturing of the grains, but no evident loss of cohesion. These experiments are the first known to the writers in which plastic flow has been induced in granite.

Basalt was deformed plastically at 300°C, dry, 5000 atmospheres confining pressure. Under a differential stress of 14,000 kg/cm², a specimen was compressed 8 per cent before the removal of the differential stress at the onset of shearing fracture.

A specimen of New Zealand dunite was deformed plastically about 2 per cent at a compressive stress of 9200 kg/cm² (300°C, dry, 5000 atmospheres confining pressure). The experiment was terminated by shearing fracture of the dunite. A similar specimen with 3.6 per cent of water broke at 2000 kg/cm² compressive stress. It is thought that the water weakened the intergranular bonds so that the specimen gradually disintegrated.

A specimen of Dover Plains dolomite supplied by Dr. E. B. Knopf was deformed plastically

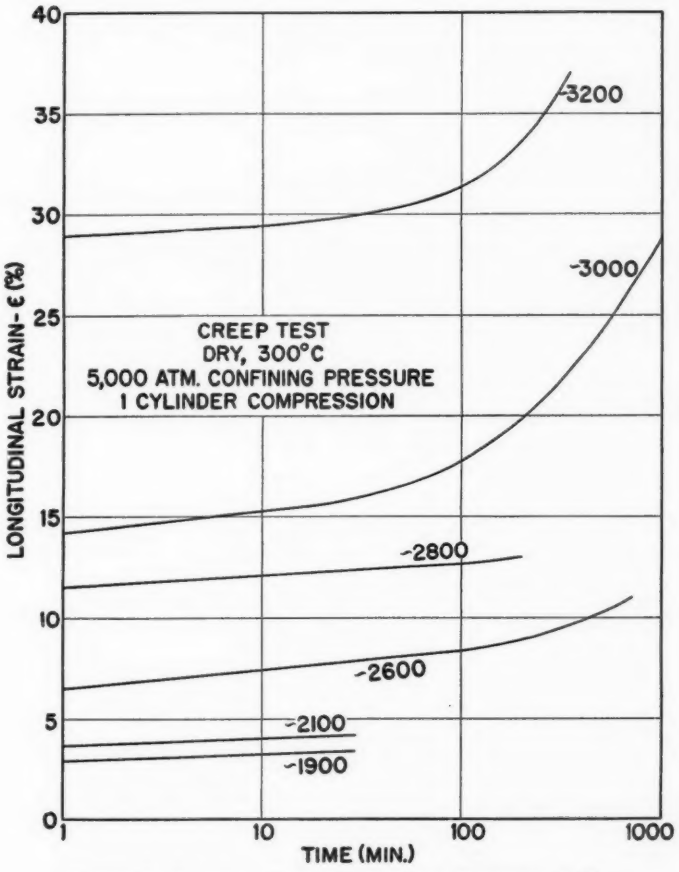

FIGURE 5.—STRAIN VS. LOGARITHM OF TIME—EXPERIMENT 400

10 per cent under a compressive stress of 7300 kg/cm² (300°C, dry, 5000 atmospheres confining pressure). The experiment was terminated by shearing fractures. This result is consistent with the extensive work on dolomite being done by Dr. John Handin at the Shell Laboratories in Houston.

The experiments described in this section were performed by Mr. Hugh Heard and Mr. Norman Coles.

Fabric of Moderately Strained Marble

General Statement

To facilitate comparison with deformed fabrics described in Parts III and IV, our observations have been concentrated on specimens shortened or elongated by about 20 per cent. These are here grouped within the general category "moderately strained marble", as contrasted with the "highly strained" specimen shortened (in creep) by 37 per cent, which is described in a subsequent section.

General Microscopic Character of Fabrics

Even as seen under a hand lens, marble deformed at 300°C has a different appearance from that deformed at lower temperatures: it lacks the chalky appearance of the latter, and the component grains of calcite have a more "glassy" aspect. In fact it begins to resemble some naturally deformed marbles. Under the microscope, cloudiness, internal strain (marked by undulatory extinction and bent lamellae), and marginal fracturing of individual grains are much less conspicuous than in specimens treated at lower temperatures (in Plate 3, *compare* A with C). Consequently even in specimens shortened or elongated by as much as 20 per cent it is possible to determine the orientation of every grain and to identify all visible lamellae and partings on the basis of angular and zonal relationships. Where twinning on $\{01\bar{1}2\}$ is highly developed, the closely spaced lamellae tend to merge locally to give nearly homogeneous, almost completely twinned areas within individual grains; whereas in specimens deformed at lower temperatures grains showing a corresponding degree of twinning are so cloudy, and the twin lamellae so closely packed that it may be impossible to locate optical and crystallographic directions precisely.

As in the specimens deformed at low temperatures, a universal consequence of deformation at 300°C is development of closely spaced visible lamellae in most grains. In this paper we discuss only the preferred orientation of $\{01\bar{1}2\}$ lamellae. Other partings and lamellae are also present in most specimens, notably those parallel to $\{10\bar{1}1\}$ and more rarely to $\{02\bar{2}1\}$ as well as abundantly developed structures irrationally oriented or parallel to high-index planes in the grain lattices. The nature and dynamic significance of all types of lamellae observed in marble deformed over the range 20°C to 300°C are discussed in Part VI (Borg and Turner, 1953).

In all specimens that have been elongated or shortened by 20 per cent or more the pattern of the intergranular surfaces, as shown in any microsection, has been modified by one or some combination of three processes—namely, flattening or elongation of grains, reduction of grain size, and development of subparallel undulating intergranular slip surfaces (*s*-surfaces of the fabric). There is marked correlation between the relative importance of these three effects in a given specimen and the orien-

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PLATE 1.—PHOTOMICROGRAPHS OF YULE MARBLE

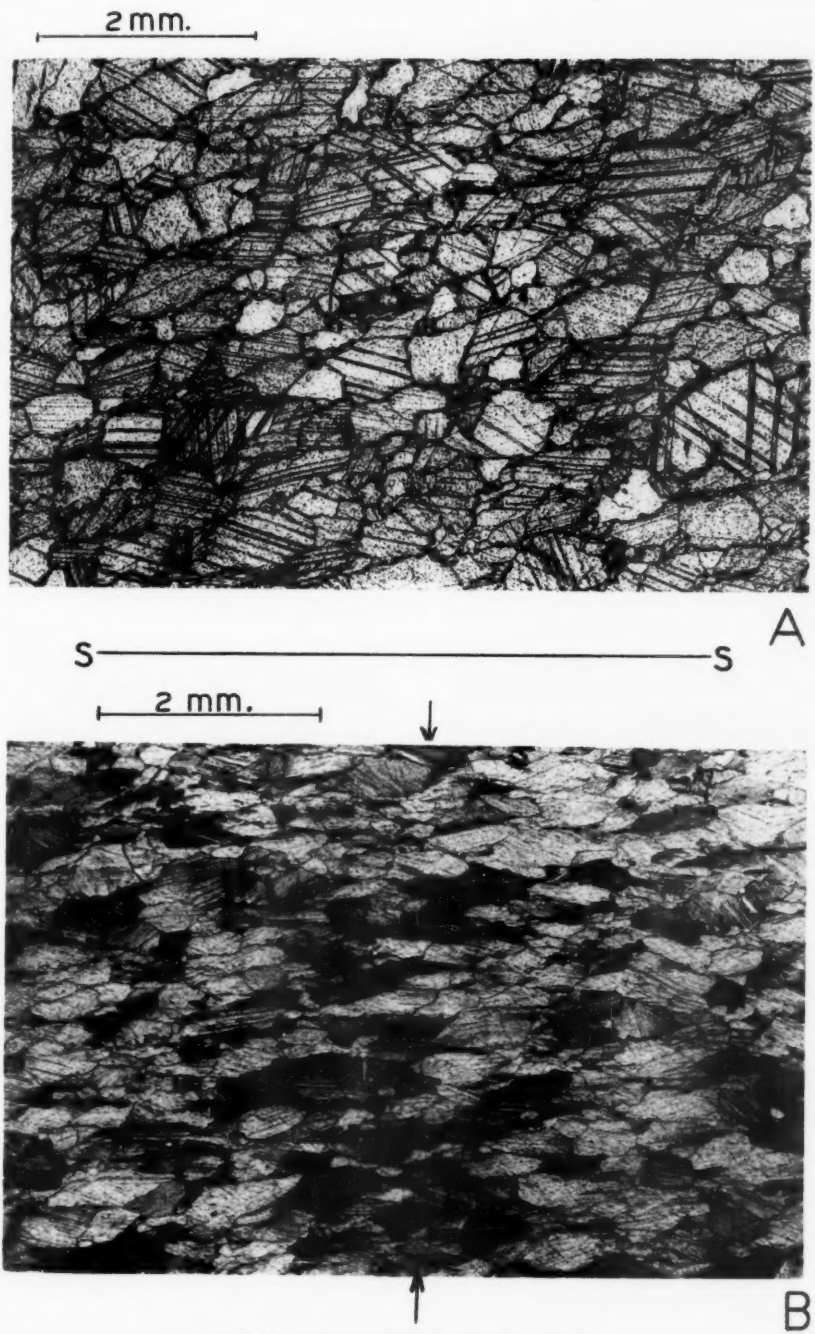
T sections; polarized light. SS = trace of initial foliation

A. Undeformed marble B. Specimen 295 (*l* cylinder) shortened 19% normal to foliation at 300°C.

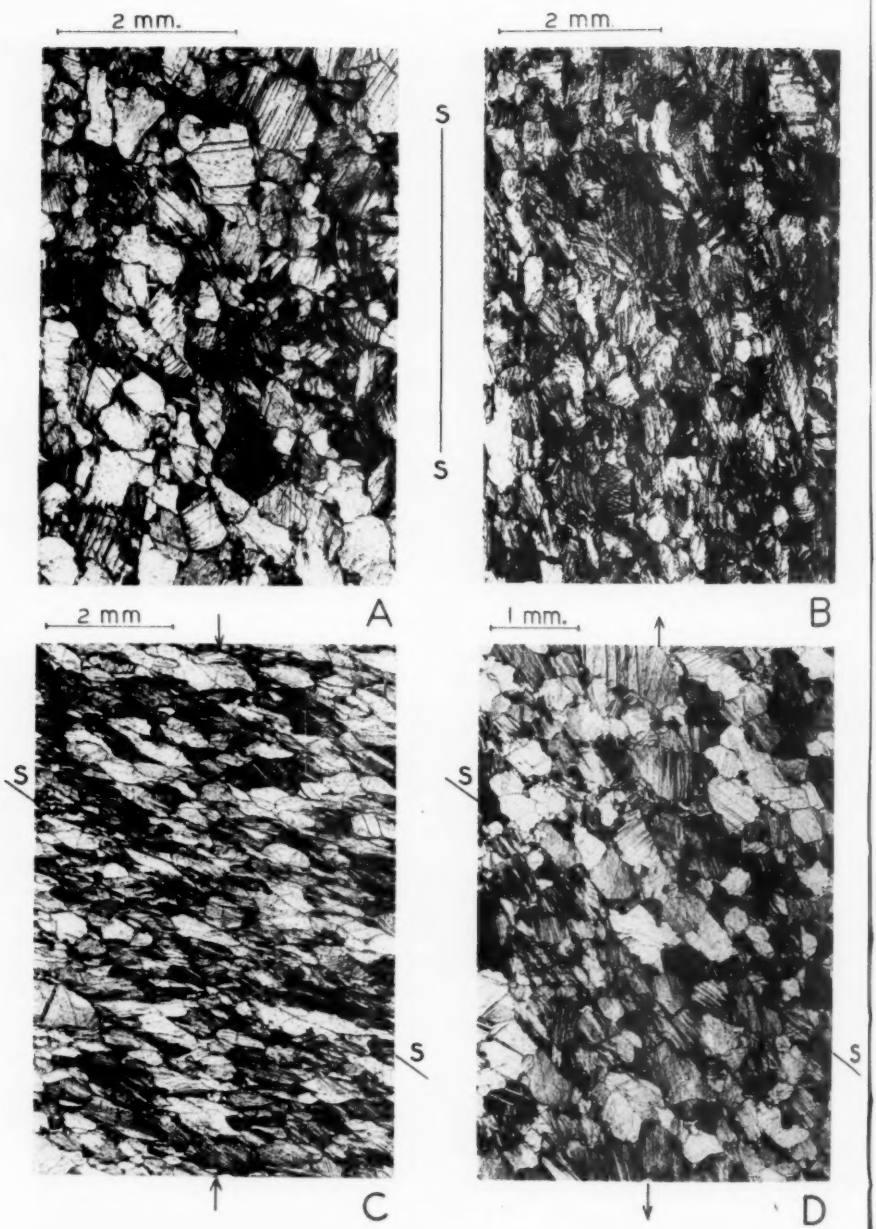
PLATE 2.—PHOTOMICROGRAPHS OF DEFORMED YULE MARBLE

T sections; polarized light. SS = trace of initial foliation

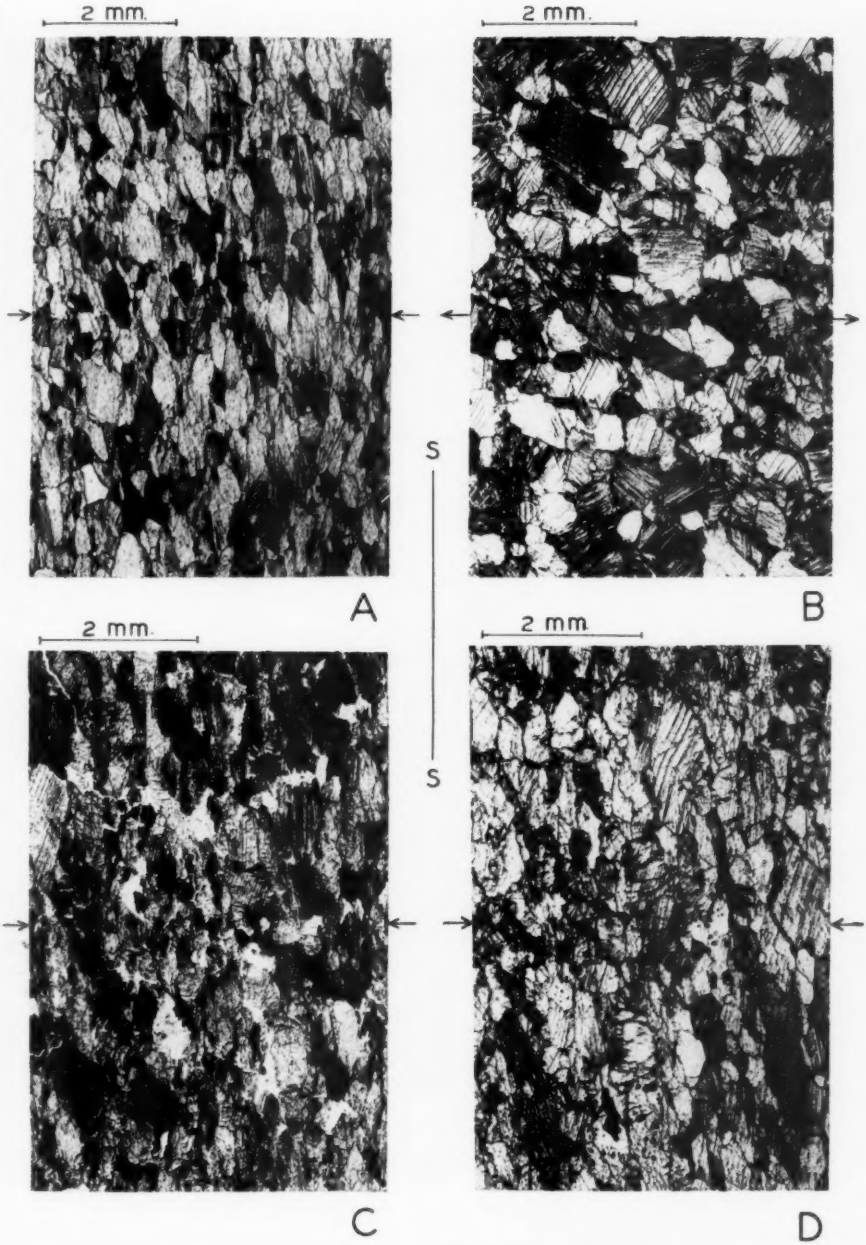
A. Specimen 365 (*T* cylinder) shortened 20% parallel to foliation, normal to plane of photograph, at 300°C. B. Specimen 358 (*T* cylinder) elongated 20% parallel to foliation, normal to plane of photograph, at 300°C. C. Specimen 272 (*d* cylinder) shortened 19% at 45° to foliation at 300°C. D. Specimen 274 (*d* cylinder) elongated 20% at 45° to foliation at 300°C.



PHOTOMICROGRAPHS OF YULE MARBLE



PHOTOMICROGRAPHS OF DEFORMED YULE MARBLE



PHOTOMICROGRAPHS OF DEFORMED YULE MARBLE

PHOTOMICROGRAPH OF DEFORMED YULE MARBLE

tation of the original fabric[2] in relation to applied stress:

(1) The most pronounced and regular change in grain shape is flattening in the plane normal to the axis of applied compression. It is shown especially by grains which, by virtue of subparallel alignment of [0001] with the axis of compression, are unable to deform by normal twin gliding on $\{01\bar{1}2\}$. This applies to the majority of grains in specimens (*1* cylinders) compressed at right angles to the initial foliation (Pls. 1B, 3A).[3] In our compression experiments the ultimate fate of all grains is to become oriented (whether by twinning and rotation or by some other means) with [0001] approaching parallelism with the axis of compression. Flattening of grains normal to this axis should then ensue. In fabrics of *d* cylinders compressed at 45° to the initial foliation the mean plane of grain elongation seems to depart somewhat from that strictly normal to the axis of compression; but this is to be expected since deformation of such specimens is compounded of axial compression plus some degree of planar shear as described below under (4). Some counterpart of the fabrics experimentally developed under compression with or without accompanying shear should be expected among the fabrics of naturally deformed rocks. It is probably significant, therefore, that natural fabrics of a simple type marked by parallel lensoid grains, for the most part lacking recognizable twins, and having [0001] inclined at high angles to the corresponding foliation, are common.

(2) In extension experiments where most grains are unfavorably oriented for twinning on $\{01\bar{1}2\}$ (*T* cylinders in extension) the tendency for grains to become elongated parallel to the axis of extension, though recognizable, is not nearly so marked as the flattening effect described above.

(3) Twin gliding on $\{01\bar{1}2\}$ must invariably result in elongation of the grain parallel to [0001]. Now in the undeformed marble many grains have their shortest dimension more or less parallel or acutely inclined to [0001]. Consequently experiments which favor deformation of most grains by twin gliding will yield fabrics in which dimensional orientation of grains must necessarily be inconspicuous. Such is the case with compression (of *T* cylinders) parallel to the foliation (Pl. 4) or extension (of *1* cylinders) normal to the foliation (Pl. 3B).

(4) Where shortening or extension takes place at 45° to the foliation (in *d* cylinders; Pl. 2C, D) the average grain size is somewhat reduced, and continuous subparallel surfaces of slip appear in the rock fabric. These *s*-surfaces are compounded of individual grain boundaries, and so are necessarily somewhat irregular. In sections cut parallel to the cylinder axis their traces intersect the latter at angles of between 30° and 60°, so that, whatever their true form, they must be surfaces of high shear stress. In compressed cylinders the traces of visible *s*-surfaces intersect the compression axis at angles greater than 45° (Pl. 2C); in elongated cylinders they intersect the axis of extension at angles less than 45° (Pl. 2D). Similar rotation of crystal glide planes toward the axis of extension and away from the axis of compression during deformation of single crystals is well known to students of metal fabrics and is theoretically predicatable for this type of experiment. (Cf. Barrett, 1943, p. 303.)

The effects described above in paragraphs

[2] Prior to deformation Yule marble has a single foliation marked by subparallel alignment of somewhat lensoid grains (Pl. 1A), and the *c* axes of the grains tend to be at angles of 50° to 90° to this foliation.

[3] All photomicrographs are taken in plane-polarized light, with analyzer out. The dark grains are ones in which internal reflection and refraction from closely spaced lamellae reduce the light transmitted.

PLATE 3.—PHOTOMICROGRAPHS OF DEFORMED YULE MARBLE

T sections; polarized light. SS = trace of initial foliation

A. Specimen 295 (*1* cylinder) shortened 19% normal to foliation at 300°C. B. Specimen 289 (*1* cylinder) elongated 18% normal to foliation at 300°C. C. Specimen 246 (*1* cylinder) shortened 20% normal to foliation at 20°C. D. Specimen 255 (*1* cylinder) shortened 19% normal to foliation at 150°C.

PLATE 4.—PHOTOMICROGRAPH OF DEFORMED YULE MARBLE

Specimen 365 (*T* cylinder) shortened 20% parallel to foliation (SS) at 300°C. *2* section; polarized light

(1)–(3) may also be observed in some of the material deformed at lower temperatures, but marginal fracturing and nonhomogeneous deformation of grains have tended to obscure the picture. Two figures illustrating the appearance

apparent tendency for stronger preferred orientation at 300°C. It is doubtful, however, if this is real. In Figure 7, diagrams A, C, E, and F represent cases where many grains show strong effects of twinning. In these, especially in the

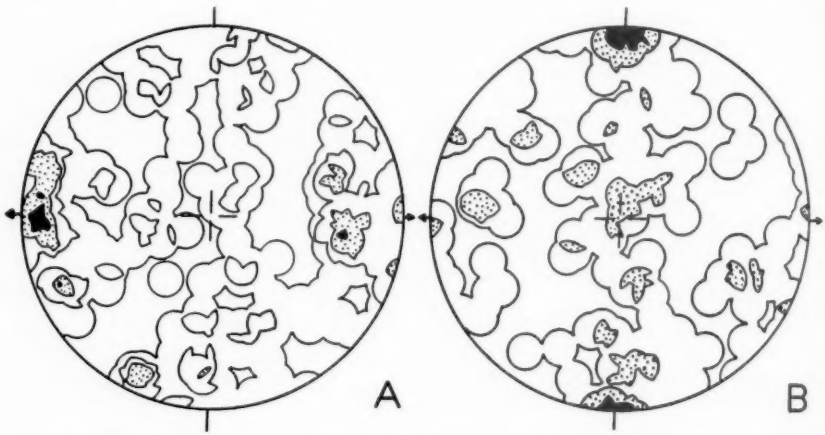


FIGURE 6.—ORIENTATION DIAGRAMS FOR *c* AXES OF CALCITE IN YULE MARBLE DEFORMED AT 300°C
Deformation of *I* cylinders by extension (E-W) normal to initial foliation.
A. Specimen 289, elongated 18%. 165 *c* axes in 150 grains (108 axes measured in *T* section, 57 axes in *2* section). Contours ½%, 1¾%, 3%, 5% per 1% area. B. Specimen 296, elongated 28%. 119 *c* axes in 100 grains. Contours 1%, 2½%, 5%, per 1% area.

of specimens deformed at 20°C and at 150°C are shown in Plate 3C and 3D.

Results of Petrofabric Analysis

Patterns of preferred orientation of [0001] axes, $\{01\bar{1}2\}$ lamellae, and $[e{:}e']$ edges closely resemble those recorded in Parts III and IV for marble correspondingly deformed at lower temperatures. It is sufficient therefore to reproduce some typical orientation diagrams for specimens elongated or shortened by about 20 per cent at 300°C (Figs. 7, 8, 9), together with brief explanatory notes as follows:

Axes [0001] show the familiar strong tendency to become aligned parallel to the axis of compression or to distribute themselves in a girdle normal to the axis of extension. For strains of 20 per cent the initial pattern of preferred orientation (an E-W marginal concentration in diagrams of Fig. 7) is not completely obliterated. Comparison with diagrams for marble correspondingly deformed at 150°C (Part IV, p. 1397, Fig. 7) in some instances shows an

high-temperature specimens, it is possible to measure directly the respective [0001] axes of the initial and of the newly twinned lattices. The apparently stronger orientation pattern of diagram A in Figure 7, as compared with Figure 7A (p. 1397) of Part IV, probably reflects the greater ease of measurement of [0001] in twinned lattices of calcite deformed at 300°C as contrasted with material similarly deformed at 150°C. In natural marble fabrics a similar difficulty arises in cases where many of the grains are strongly twinned. In Figure 6, diagrams for similarly oriented specimens (extension perpendicular to foliation) elongated respectively by 18 per cent and by 28 per cent at 300°C are compared. These diagrams illustrate progressive elimination of the initial E-W concentration of [0001] and establishment of a girdle in the N-S plane normal to the axis of extension. It is obvious that in the more deformed specimen twinning has proceeded so far in most grains that the newly twinned lattice is dominant and the [0001] axis of that

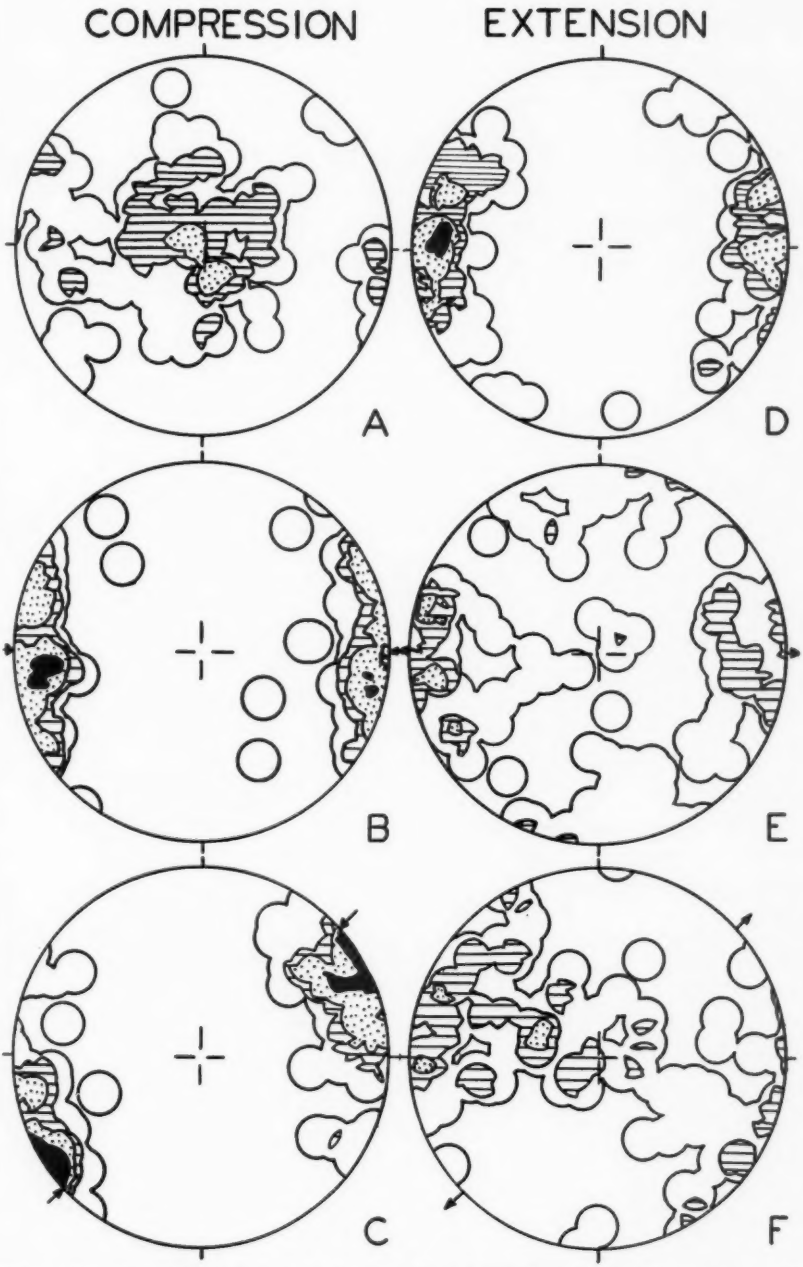


FIGURE 7.—ORIENTATION DIAGRAMS FOR *c* AXES OF CALCITE IN YULE MARBLE DEFORMED AT 300°C

100 grains per diagram. Contours 1%, 3%, 5%, 10%, per 1% area. Trace of original foliation (normal to plane of diagrams) is N-S. Plane of diagrams is T plane of marble block.

A. Specimen 365, *T* cylinder, shortened (normal to plane of diagram) by 20%; 116 *c* axes. B. Specimen 295, *I* cylinder, shortened (E-W) by 19%; 102 *c* axes. C. Specimen 272, *d* cylinder, shortened (NE-SW) by 19%; 107 *c* axes. D. Specimen 358, *T* cylinder, elongated (normal to plane of diagram) by 20%; 100 *c* axes. E. Specimen 289, *I* cylinder, elongated (E-W) by 18%; 108 *c* axes. F. Specimen 274, *d* cylinder, elongated (NE-SW) by 20% 114 *c* axes.

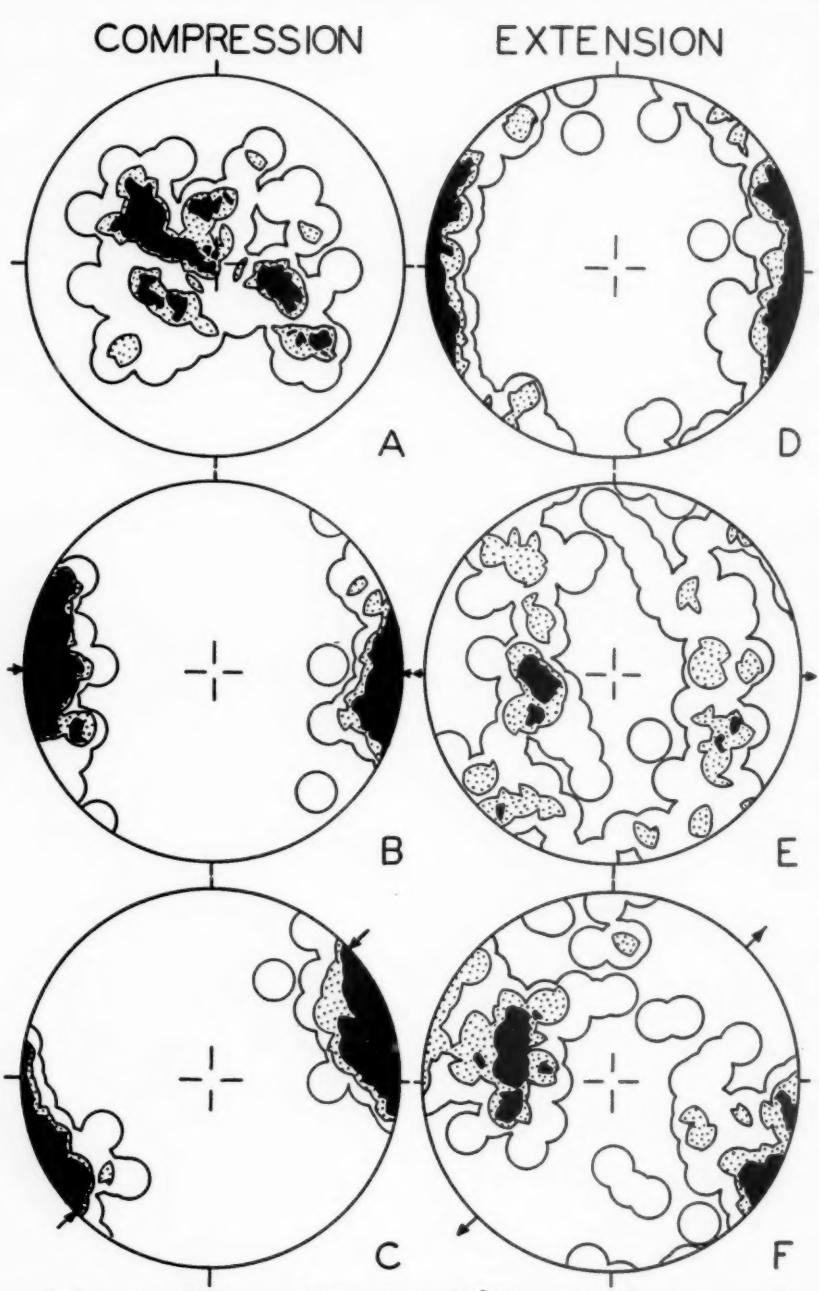


FIGURE 8.—ORIENTATION DIAGRAMS FOR BEST-DEVELOPED {01$\bar{1}$2} LAMELLAE OF CALCITE IN YULE MARBLE DEFORMED AT 300°C

100 grains per diagram. Contours approximately 1%, 3%, 4%, per 1% area. Trace of original foliation (normal to plane of diagrams) is N-S. Plane of diagrams is T plane of marble block.

A. Specimen 365, *T* cylinder, shortened (normal to plane of diagram) by 20%; 106 sets of lamellae. B. Specimen 295, *I* cylinder, shortened (E-W) by 19%; 86 sets of lamellae. C. Specimen 272, *d* cylinder, shortened (NE-SW) by 19%; 96 sets of lamellae. D. Specimen 358, *T* cylinder, elongated (normal to plane of diagram) by 20%; 115 sets of lamellae. E. Specimen 289, *I* cylinder, elongated (E-W) by 18%; 120 sets of lamellae. F. Specimen 274, *d* cylinder, elongated (NE-SW) by 20%; 112 sets of lamellae.

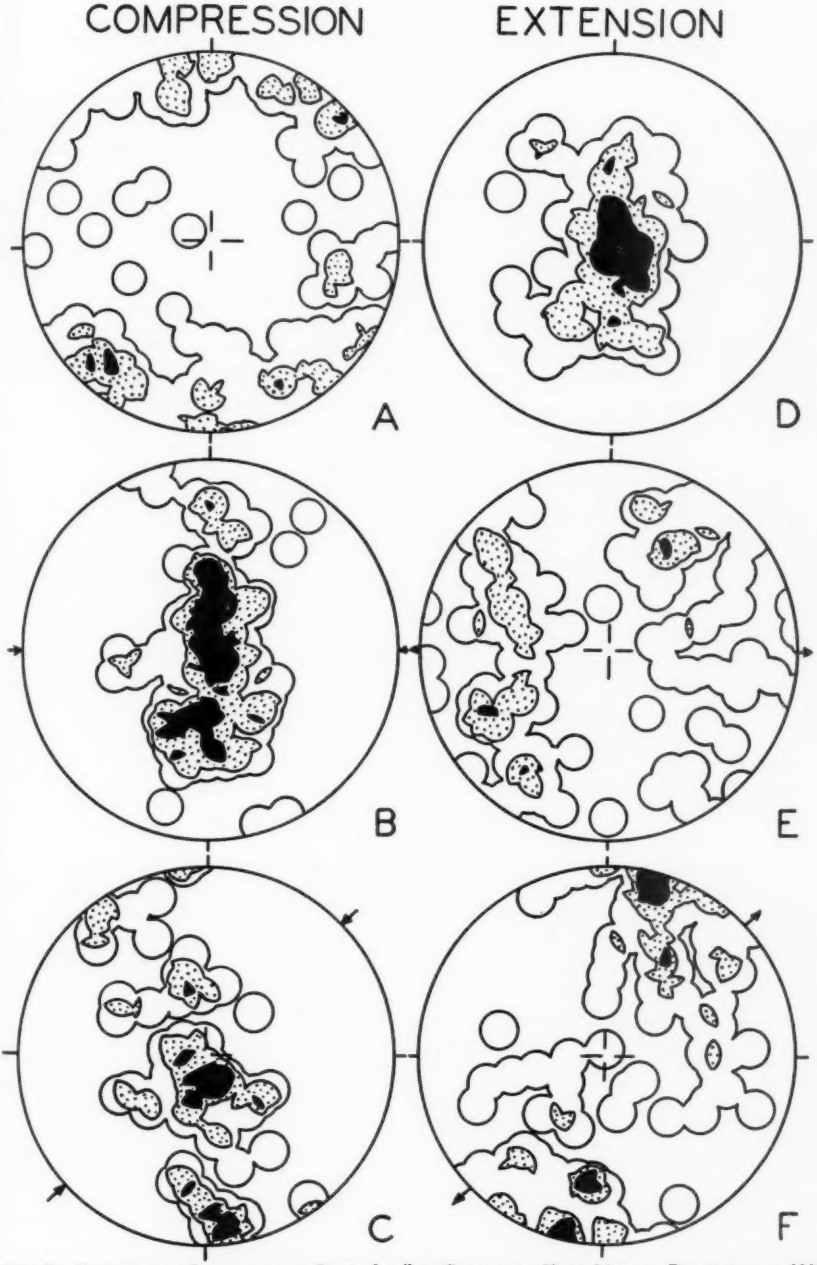


FIGURE 9.—ORIENTATION DIAGRAMS FOR EDGES [*e*:*e*'] IN CALCITE OF YULE MARBLE DEFORMED AT 300°C

100 grains per diagram. Contours, 1%, 3%, 6% per 1% area. Trace of original foliation (normal to plane of diagram) is N-S. Plane of diagrams is T plane of marble block.

A. Specimen 365, *T* cylinder, shortened (normal to plane of diagram) by 20%; 102 edges. B. Specimen 295, *I* cylinder, shortened (E-W) by 19%; 66 edges. C. Specimen 272, *d* cylinder, shortened (NE-SW) by 19%; 64 edges. D. Specimen 358, *T* cylinder, elongated (normal to plane of diagram) by 20%; 95 edges. E. Specimen 289, *I* cylinder, elongated (E-W) by 18%; 100 edges. F. Specimen 274, *d* cylinder, elongated (NE-SW) by 20%; 94 edges.

lattice has therefore been recorded rather than [0001] of the initial lattice.

Diagrams for strongly developed $\{01\bar{1}2\}$ lamellae are shown in Figure 8. In most grains one set of lamellae is clearly more conspicuous than the other two, and this set is then plotted on the diagram. A few grains show two equally developed sets, both of which are then plotted, while in a few others no lamellae are strong enough to be included. The number of lamellae plotted for 100 measured grains ranges from 86 to 120. The majority of $\{01\bar{1}2\}$ lamellae plotted in diagrams A and E of Figure 8 are optically recognizable as products of twinning. This is to be expected since in both cases the specimen was oriented so as to favor twin gliding in most grains. In each case the pattern consists of a ring maximum (or cleft girdle of small radius) surrounding the axis of compression or extension. These diagrams are to be contrasted with B and D of Figure 8, in which the plotted lamellae are not optically recognizable as twins. They may be termed nontwinned sets of $\{01\bar{1}2\}$ lamellae; and their poles give either a strong maximum coinciding with the axis of compression, or a sharp girdle in the plane normal to the axis of extension. Diagrams C[4] and F of Figure 8 represent a mixture of twinned and nontwinned sets of lamellae and in some respects combine the qualities of the other two types of diagram. Distinction between $\{01\bar{1}2\}$ lamellae of the twinned and the nontwinned types in natural marble fabrics obviously may be important. Preliminary work on natural marbles by F. J. Turner, D. B. McIntyre, and L. Weiss confirms this conclusion.

Preferred orientation of edges $[e{:}e']$ between the two strongest sets of $\{01\bar{1}2\}$ lamellae shown by most grains is illustrated in Figure 9. The diagrams almost duplicate those for marble deformed at 150°C (Part IV, Fig. 10, p. 1400). Insofar as is permitted by the orientation of the grain lattices, edges $[e{:}e']$ are concentrated at high angles to the axis of compression or subparallel to the axis of extension.

[4] The exact position of the axis of compression in diagram C is not certain since the specimen shows some degree of bending and is deformed by a combination of axial compression plus diagonal shear. The compression axis possibly is as much as 10° nearer the E-W diameter of the diagram than is shown by the arrow.

Fabric of Highly Strained Marble

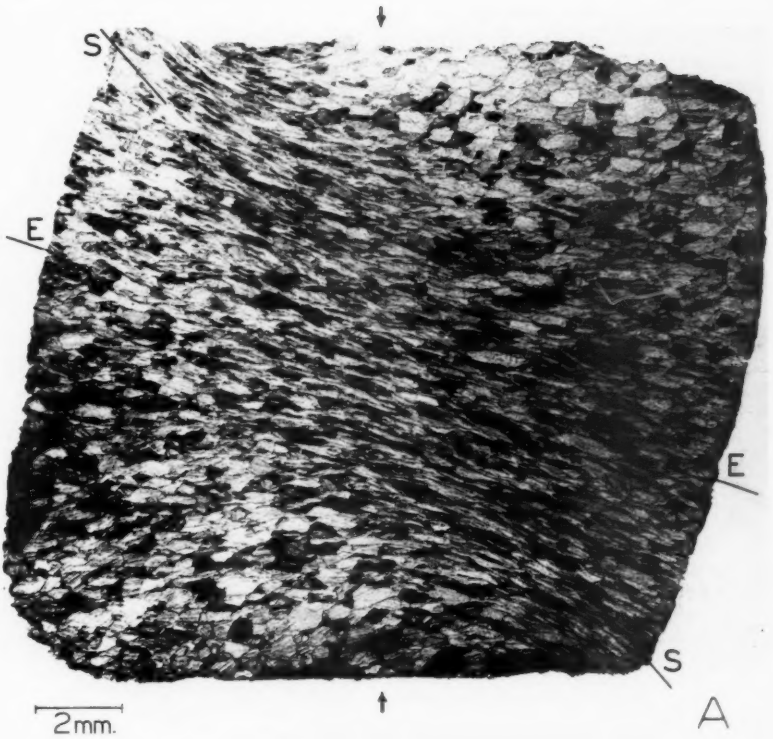
The general character of the fabric of specimen 400 (*1* cylinder), shortened 37 per cent by compression applied normal to the initial foliation during a slow run of 48 hours duration, is shown in Plate 5. In this experiment deformation was a compound type involving radial flattening in the plane normal to the compression axis, plus shear along a diagonal zone SS. Outside the shear zone the individual grains become elongated at right angles to the compression. But within the shear zone they become reduced in size, very greatly elongated, and dimensionally aligned in a new *s*-plane or foliation, EE. Grains in the almost undeformed marble at the extreme ends of the specimen have typical dimensions (0.5 mm. by 0.3 mm.) to (1 mm. by 0.5 mm.). In the shear zone typical dimensions range between (0.2 mm. by 0.05 mm.) and (1 mm. by 0.25 mm.). Other evidences of strain are strongly undulatory extinction (the extinction bands being approximately parallel to $\{10\bar{1}1\}$ of the grain lattice) and conspicuous dark nontwinned $\{01\bar{1}2\}$ lamellae. There is usually one prominent set of these per grain, though the other two may be feebly developed. In many grains the lamellae are confined to one local area within the grain in question. In some grains $\{01\bar{1}2\}$ lamellae are bent as they cross successive extinction bands; but within any band the lamellae maintain a normal orientation in the lattice. As is to be expected from the orientation of the specimen, only a minor proportion of grains show recognizable twinning on $\{01\bar{1}2\}$; but in these twinning is highly complex.

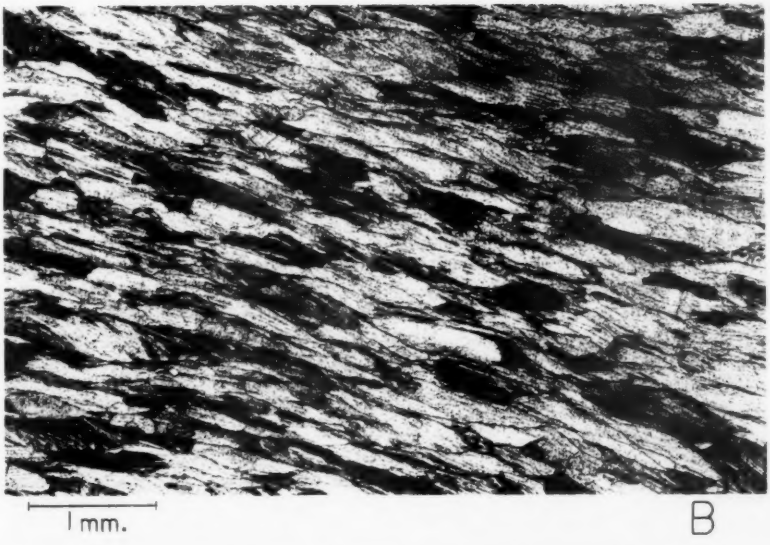
Results of petrofabric analyses are shown in

Plate 5.—Photomicrographs of Highly Deformed Yule Marble

Specimen 400 (*1* cylinder) shortened 37% normal to foliation at 300°C. (duration of run, 48 hours). Initial foliation is E–W, normal to plane of photograph. SS = shear zone. EE = mean direction of elongation of grains.

A. *2* section of complete cylinder. B. Enlargement of central part of shear zone of A.





PHOTOMICROGRAPHS OF HIGHLY DEFORMED YULE MARBLE

Figure 10. The orientation diagram for [0001] axes (Fig. 10A) is based on measurements of the mean position of the optic axis in each of 100 grains[5] (in every grain the crystal structure is so strained that the position of [0001] varies through a range of 10° or more). Orientation of strongly developed nontwinned $\{01\bar{1}2\}$ lamellae in the same grains is illustrated in Figure 10B. Both diagrams give a very strong maximum coinciding with the pole of the new foliation plane EE, though the lamella-pole maximum is the sharper and stronger of the two. Thus there is a very pronounced tendency for both [0001] and the normal to visible nontwinned $\{01\bar{1}2\}$ lamellae to lie at a high angle (approaching 90°) to the AB plane of the strain ellipsoid of marble deformed by combined shear and compression under the conditions of this particular experiment. This AB plane (EE of Plate 5 and Figure 10) occupies a position between the plane of shear SS and the plane normal to applied compression. Similar relations between grain elongation, orientation of [0001], parallel alignment of $\{01\bar{1}2\}$ lamellae, axis of compression, and orientation of *s* surfaces of shear are seen in "moderately strained" specimens compressed at 45° to the initial foliation. (*Cf.* Plate 2C, and Figures 7C and 8C.)

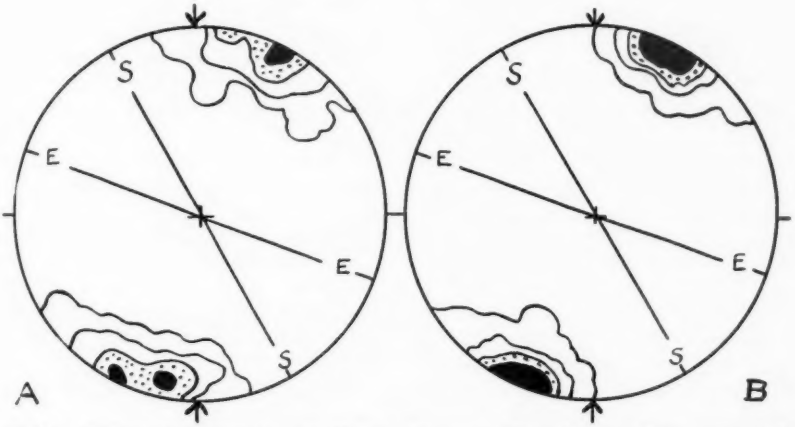


FIGURE 10.—ORIENTATION DIAGRAMS FOR HIGHLY DEFORMED YULE MARBLE DEFORMED AT 300°C

Specimen 400 (*1* cylinder) shortened 37% by compression (indicated by arrows) applied normal to initial foliation. SS = shear zone. EE = mean direction of elongation of grains.

A. 100 [0001] axes in 100 grains. Contours 1%, 5%, 10%, 15%, per 1% area. B. 103 poles of prominent $\{01\bar{1}2\}$ lamellae in 100 grains. Contours 1%, 5%, 10%, 20% per 1% area. Maximum concentration, 40%.

[5] These grains lie on three widely separated traverses across the shear zone SS. Half of them lie within the area embraced by Plate 5B. In comparing Figure 10 with Figures 7B and 8B, note that the contour intervals are different.

Two possibly significant analogies are noted in conclusion. Single crystals of calcite deformed by compression, either parallel to [0001] at 20°C or normal to $\{01\bar{1}2\}$ at 300°C, develop undulatory extinction bands bounded by $\{10\bar{1}1\}$ surfaces and crowded internally with nontwinned $\{01\bar{1}2\}$ lamellae. Many natural marbles are composed of strongly elongated grains of calcite whose parallel alignment defines a single prominent foliation. In some such rocks [0001] is strongly concentrated in the vicinity of the pole of the foliation plane, and there is a similar maximum for poles of nontwinned sets of $\{01\bar{1}2\}$ lamellae. The pattern of such fabrics is in many ways similar to that just described for our experimentally deformed specimen. To assume that simple compression normal to the foliation is necessarily responsible for natural marble fabrics of this general type is obviously unwarranted.

CONCLUSION

The most pronounced difference between Yule marble deformed at 300°C and that de-

formed at room temperature and at 150°C is the microscopic appearance of thin sections of the deformed material. These differences can most aptly be summarized by saying that the marble deformed at 300°C looks like naturally deformed marble, while that deformed at room temperature definitely does not, and the 150°C material is intermediate between the two.

The mechanism of deformation is definitely different at 300°C. The hypothesis of twin and translation gliding on $\{01\bar{1}2\}$ does not provide correlation of the stress-strain data as it did at the lower temperatures. The predicted fabrics of Part II, however, agree with those here observed within the statistical sampling error.

The microscopic evidence indicates intergranular motion in these experiments at 300°C. The development of intergranular slip surfaces, the reduction in grain size, and the lack of marginal distortion at grain boundaries leave little doubt that some intergranular flow or recrystallization has occurred. These effects are most pronounced in the specimen deformed 37 per cent in 48 hours.

Preliminary studies of single crystals of calcite deformed at 300°C indicate that translation on $\{10\bar{1}1\}$ is the most important mechanism in addition to twinning on $\{01\bar{1}2\}$. This translation can be distinguished only with difficulty under the microscope, so that while the evidence from fabric studies of Yule marble deformed at 300°C does not prove that $\{10\bar{1}1\}$ translation is important, it is consistent with such an interpretation.

It is concluded that three mechanisms of deformation are roughly of equal importance at 300°C: (1) twin gliding on $\{01\bar{1}2\}$; (2) translation gliding on $\{10\bar{1}1\}$; and (3) intergranular flow (recrystallization). The first mechanism is most important in reorienting fabrics initially so oriented as to favor twin gliding. The last two mechanisms produce smaller changes in crystallographic orientation for a small amount of deformation, but predominate at high deformations.

The trend of fabric changes is similar to that observed at room temperature and at 150°C. In orientation diagrams for fabrics formed by uniaxial compression or extension, *c*-axes maxima and *e*-lamella-pole maxima tend to occur at the point of emergence of the compression axis or within a girdle normal to the axis of extension. In addition, diagrams for fabrics developed by deformation involving shearing strain at 300°C have *c*-axes maxima and *e*-lamella-pole maxima tending to coincide with the pole of the AB (largest) plane of the strain ellipsoid.

Interstitial water seems, as at 150°C, to have principally mechanical effects. There is no evidence as yet that interstitial water has any appreciable effect on intergranular flow or recrystallization. The effect of time, or rate of strain, has not been strictly segregated in these experiments, but it appears likely that at 300°C longer time favors intergranular motion.

Granite, basalt, dunite, and dolomite are somewhat plastic at 300°C, 5000 atmospheres confining pressure. For short periods of time granite and basalt will support differential compressive stresses some 5 times their normal laboratory strength as measured at atmospheric pressure.

Work at 400 and 500°C is now under way.

References Cited

Barrett, C. S., 1943, Structure of metals: McGraw-Hill, New York.

Borg, Iris, and Turner, F. J., 1953, Deformation of Yule marble, Part VI: Geol. Soc. America Bull., vol. 64, p. 1343–1352.

Griggs, D. T., 1940 Experimental flow of rocks under conditions favoring recrystallization: Geol. Soc. America Bull., vol. 51, p. 1001–1022.

Griggs, D. T., and Miller, W. B., 1951, Deformation of Yule marble, Part I: Geol. Soc. America Bull., vol. 62, p. 853–862.

Griggs, D. T., Turner, F. J., Borg, I., and Sosoka, J., 1951, Deformation of Yule marble, Part IV: Geol. Soc. America Bull., vol. 62, p. 1385–1406.

Handin, J. W., 1953, An application of high pressure in geophysics: Experimental rock deformation: Am. Soc. Mech. Eng. Trans., vol. 75, p. 315–324.

Handin, J. W., and Griggs, D. T., 1951, Deformation of Yule Marble, Part II: Geol. Soc. America Bull., vol. 62, p. 863–886.

Turner, F. J., and Ch'ih, C. S., 1951, Deformation of Yule marble, Part III: Geol Soc. America Bull., vol. 62, p. 887–906.

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DEFORMATION OF YULE MARBLE: PART VI— IDENTITY AND SIGNIFICANCE OF DEFORMATION LAMELLAE AND PARTINGS IN CALCITE GRAINS

BY IRIS BORG AND FRANCIS J. TURNER

ABSTRACT

By far the commonest lamellar structures occurring in calcite of Yule marble deformed at 20° to 300°C are parallel to $\{01\bar{1}2\}$. Some of these are recognizable as twin lamellae, but many lack definite criteria of twinning. Three types of anomalous lamellae, differing distinctly from $\{01\bar{1}2\}$ in their angular relations to [0001] and to other recognizable lattice directions, are also common in some deformed specimens. Lamellar structures parallel to $\{02\bar{2}1\}$ and $\{10\bar{1}1\}$ and cracks subparallel to $\{10\bar{1}0\}$ have also been noted.

This paper summarized information as to criteria (appearance and crystallographic orientation) for recognition of the various types of lamellae, and the stress environments in which each tends to develop. A synopsis of this information is appended (Table 2).

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INTRODUCTION

More than fifty years ago Adams and Nicolson (1901) described in detail the changes in microscopic fabric of marble, induced by plastic deformation in the laboratory at temperatures ranging up to 300°C. They recorded three visible effects: flattening and elongation of individual grains of calcite; appearance of swarms of lamellae attributed to twinning on $\{01\bar{1}2\}$; cataclastic granulation along a network of cracks traversing the marble fabric. They concluded that "gliding movements in the individual crystals" were responsible for the shape of elongated grains lacking visible $\{01\bar{1}2\}$ lamellae; and they seem to have envisaged twinning as a common but not indispensable accompaniment of such gliding.

The fabric of Yule marble specimens used by Griggs (1936) in his first series of compression experiments was studied in great detail by E. B. Knopf (1949) using universal-stage technique. Taking as a criterion the angle between the c axis of a calcite grain and the pole of an observed lamella, she identified the planar structures (lamellae) measured in the deformed marbles as belonging to 5 different types—namely $\{01\bar{1}2\}$, $\{10\bar{1}1\}$, $\{10\bar{1}0\}$, $\{02\bar{2}1\}$, and $\{0001\}$ (Knopf, 1949, p. 547, 554).

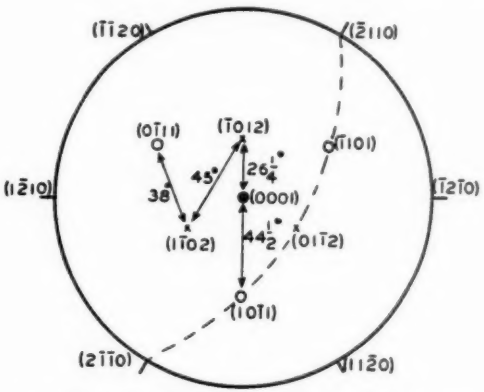

FIGURE 1.—EQUAL-AREA PROJECTION (upper Hemisphere) FOR CALCITE

The present paper summarizes our observations on lamellae in specimens of Yule marble experimentally deformed by David Griggs and collaborators at the Institute of Geophysics of the University of California at Los Angeles during the period 1949–1952. Conditions and results of Griggs' experiments, and petrofabric analysis of the materials deformed by him are recorded in Parts I to V of this series of papers (Griggs and Miller, 1951; Handin and Griggs, 1951; Turner and Ch'ih, 1951; Griggs *et al.*, 1951; Griggs *et al.*, 1953). Our conclusions regarding lamellae are based on experience gained by ourselves and C. S. Ch'ih in the course of petrofabric analyses of some 30 specimens during the past 3 years.

ACKNOWLEDGMENTS

We are glad to acknowledge liberal financial support from the Penrose Bequest of The Geological Society of America and from the Office of Naval Research, United States Department of the Navy.[1] We are indebted also to Dr. C. S. Ch'ih, whose earlier observations on lamellae in marble deformed at 20°C helped to provide the foundation for this paper, and to Professor David Griggs who supplied us with all the material described.

LAMELLAE PARALLEL TO $\{01\bar{1}2\}$

Every petrographer is familiar with lamellae, conventionally recorded as "twin lamellae," parallel to $\{01\bar{1}2\}$ surfaces of calcite grains in marbles. The same structures appear in great profusion in marble deformed in the laboratory. They can be studied most satisfactorily in specimens deformed at 300°C, for in this material the component grains show minimal clouding, marginal fracturing, and internal strain. In any grain the appropriate angular and zonal relationships between observed c axis, $\{10\bar{1}1\}$ cleavages, and $\{01\bar{1}2\}$ lamellae, as plotted on a projection (Fig. 1), hold with sufficient accuracy to establish the identity of all three. However, there is a constant discrepancy regarding values observed for the angle c to $\{01\bar{1}2\}$. These vary within 3°–4° of the ideal angle, 26¼°, and in most cases tend to lie between 28° and 30°. Cumulative error involved in locating c axes and $\{01\bar{1}2\}$ lamellae is probably the main, if not the sole, cause of variation. Similar dis-

[1] Contract Nonr-222(08); project NR 081 134.

crepancies have been noted in the case of natural marble fabrics.

For details regarding mode of development of {01$\bar{1}$2} lamellae, the reader is referred to Parts III (p. 895–901), IV (p. 1393–1395, 1398), and V. The following generalizations apply to marble fabrics developed throughout the range of Griggs' experiments:

(1) Lamellae in some cases are broad enough to allow twinning to be clearly recognized by symmetrical differences in optical behavior (*e.g.*, extinction) of adjacent lamellae in a grain (Pl. 2A). Only lamellae of this type are here termed *twin lamellae*. There is another type of {01$\bar{1}$2} lamella which, when brought parallel to the axis of the microscope tube, is so thin that it appears as a sharp planar parting (Pl. 1A). It is impossible to tell by optical means whether these are twin lamellae of exceeding thinness, or whether they are due to some mechanism other than twinning. They are common, too, in many natural marbles (*cf.* Turner, 1949, p. 600; Sander, 1950, p. 232–236), and they are here designated *nontwinned lamellae*.

(2) In most calcite grains one set of lamellae is conspicuous, a second set is somewhat less so, and the third is weakly developed or absent. In this paper these are designated e_1, e_2, and e_3, respectively. In some grains e_1 and e_2 are equally prominent, while in others e_1 alone is well developed.

(3) Prominent sets of {01$\bar{1}$2} lamellae (e_1 and e_2) range from those which consist entirely of twin lamellae (usually .01 mm to .03 mm in width) to sets composed entirely of nontwinned lamellae. For statistical purposes we may recognize four categories of lamella sets with mutual gradations:

(a) Nontwinned lamellae only, rather widely spaced compared with other sets of lamellae in the same marble specimen. Without prejudice as to mechanism of origin, we term these *nontwinned* sets of lamellae (Pl. 1A).

(b) Densely spaced nontwinned lamellae accompanied by minor narrow twin lamellae. These are designated *dense sets with minor twinning* (Pl. 1B).

(c) Densely spaced narrow twin lamellae accompanied by some nontwinned lamellae. A considerable percentage (perhaps 30–50 per cent) of the total area of the grain is recognizably twinned in relation to the remainder. These are termed *dense strongly twinned* sets of lamellae (Pl. 1C, upper half).

(d) *Completely twinned* areas with residual lamellae. These areas are end products of the twinning process, and they usually occur as local patches within grains which elsewhere show lamellae of type (c) (Pl. 1C). There is reason to suspect from other evidence that some grains with comparatively few lamellae are actually approaching the completely twinned condition.

(4) In specimens of Yule marble compressed parallel or extended normal to the foliation, the system of applied stress is such as to favor twin gliding on at least one set of {01$\bar{1}$2} surfaces in most grains. Sections of such specimens show many grains with dense strongly twinned sets of lamellae. For relatively slight total strain (3–7 per cent) there is strong correlation between the degree of development (spacing index) of each of the three sets of {01$\bar{1}$2} twin lamellae in a grain and the coefficient of resolved shear stress (in the appropriate sense for twin gliding) along the glide line (01$\bar{1}$2):(10$\bar{1}$1) within the {01$\bar{1}$2} plane in question. (*Cf.* Part II, p. 866–869.) Where elongation or shortening of the specimen is about 20 per cent, many grains show nearly complete twinning on that set of {01$\bar{1}$2} surfaces for which the coefficient of resolved shear stress appropriate for twin gliding is maximal.

(5) In specimens compressed normal or elongated parallel to the foliation, the resolved shear stresses on all three {01$\bar{1}$2} surfaces of most grains act in the sense opposite to that associated with twin gliding. In marble so deformed, e_1 sets of lamellae in most grains are either nontwinned or belong to the ctageory of dense sets with minor twinning. The latter become increasingly abundant as the degree of deformation of the specimen increases. For relatively low strains (3–10 per cent) there is an inexplicable but consistent correlation between degree of development (spacing index) of sets of lamellae and coefficient of resolved shear stress along the corresponding glide direction (01$\bar{1}$2):(10$\bar{1}$1). The most conspicuous (most closely spaced) lamellae are those for which

the resolved shear stress coefficient approaches zero. (*Cf.* Part III, p. 899, Fig. 6, no. 154.) They tend to be perpendicular to the compression axis or parallel to the axis of extension—*i.e.*, in all cases normal to the maximum compressive stress.

Anomalous Planar Structures Related to $\{01\bar{1}2\}$

General Statement

Careful determination of interfacial angles and zonal relations between lamellae commonly reveals striking anomalies with respect to lamellae which at first sight would be identified as belonging to $\{01\bar{1}2\}$. These anomalies apply to material covering the whole range of experimental conditions. The lamellae concerned belong to three types individually recognizable by their respective angular relations to the c axes of grains in which they occur. We have designated them descriptively as L_1, L_2, and L_3. One type, L_1, is confined to untwinned or slightly twinned grains; L_2 is found only in grains with strongly developed lamellar twinning on $\{01\bar{1}2\}$; L_3 occurs only in grains believed to be almost completely twinned. All have been observed in appropriate specimens deformed at 20°C and at 150°C; but it is only in material deformed at 300°C that grains are sufficiently clear and homogeneously strained to allow satisfactory investigation of the nature and relations of anomalous lamellae.

Anomalous Lamellae L_1

Lamellae designated L_1 (Pl. 1B) occur as sharp planar structures intersecting associated visible $\{01\bar{1}2\}$ lamellae at very acute angles—typically 5° to 11°. On this account they were previously given the notation e' (Part IV, p. 1394); but the descriptive designation L_1 is now substituted to avoid confusion with $\{01\bar{1}2\} = e$. The angle L_1 to $\{0001\}$ in most if not in all cases is less than 26°.

The L_1 structures resemble nontwinned $\{01\bar{1}2\}$ lamellae in their rectilinear character and ultramicroscopic thinness. Very rarely they are thick enough for differences in optic orientation of lamella and host crystal, suggestive of twinning, to be recognized. There is nothing to indicate whether they are products of gliding under shear stress or fractures analogous to cleavages.

Lamellae L_1 consistently occur in grains so situated in the stress field that twin gliding on any of the three $\{01\bar{1}2\}$ planes of the lattice is impossible. They are commonest therefore in cylinders shortened normal or elongated parallel to the foliation. In any individual grain L_1 approximates one of the well-developed sets of $\{01\bar{1}2\}$ lamellae—in most cases that for which the spacing index is highest. Since we are concerned with grains whose $\{01\bar{1}2\}$ lamellae are essentially nontwinned, it follows that the coefficient of resolved shear stress, in the glide direction $(01\bar{1}2):(10\bar{1}1)$, tends to be low for that $\{01\bar{1}2\}$ surface with which L_1 is associated. This is illustrated in Table 1 which gives resolved shear stress coefficients calculated for $\{01\bar{1}2\}$ planes in 10 grains showing L_1 selected at random.

The significance of L_1 lamellae remains uncertain. We have concluded from earlier preliminary observations (Part IV, p. 1394) that two alternative modes of origin, neither completely consistent with all observations, are open to consideration: (1) They may be partings or twin lamellae inherited from the undeformed fabric and rotated, without distortion, through

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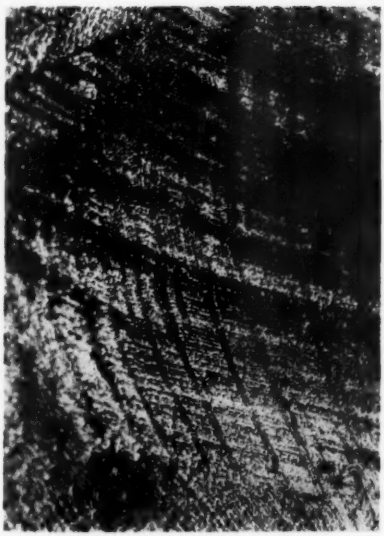
Plate 1.—Lamellae in Experimentally Deformed Yule Marble

(Polarized Light)

(a) Nontwinned lamellae $\{01\bar{1}2\}$; two sets. The horizontal set is not exactly perpendicular to the plane of the photograph. × 127. (b) Densely spaced nontwinned lamellae and narrow twin lamellae $\{01\bar{1}2\}$ cut acutely by anomalous lamellae L_1. × 156. (c) Near-horizontal twin lamellae $\{01\bar{1}2\}$ with twinning approaching completion in lower half of grain. A second (vertical) set of $\{01\bar{1}2\}$ lamellae in the upper part is rotated into the anomalous L_2 position in the lower part of the grain. (Nicols crossed.) × 120. (d) Grain with nearly complete twinning on closely spaced near-horizontal $\{01\bar{1}2\}$ lamellae. Two sets of L_2 lamellae lie parallel to the diagonals of the photograph. Note the lamellar structure within the broad NW-SE lamella L_2 in the bottom left portion of the photograph. × 156.

A

B



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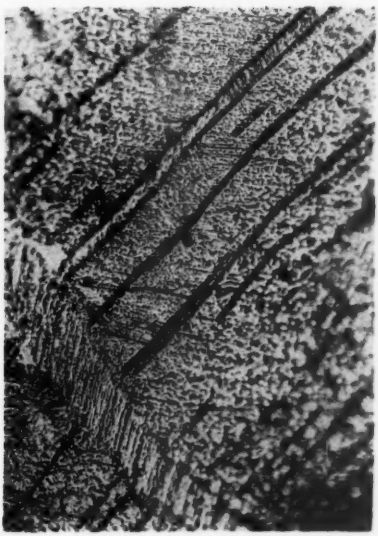
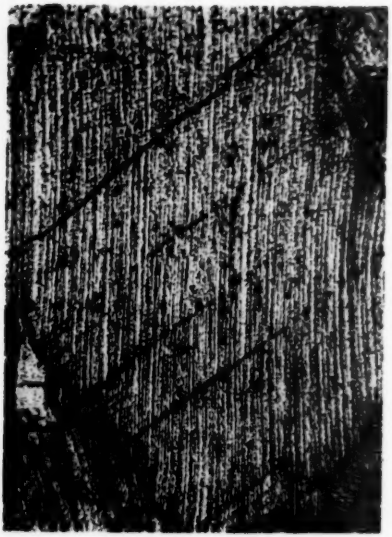


D

LAMELLAE IN EXPERIMENTALLY DEFORMED YULE MARBLE



A

B

C

D

LAMELLAE IN EXPERIMENTALLY DEFORMED YULE MARBLE

the crystal lattice to their present anomalous position, as a result of translation gliding on other planes—*e.g.*, another {01$\bar{1}$2} plane, or {10$\bar{1}$1}. (2) The lamellae L_1 may have formed at a late stage by gliding on irrational or high-index surfaces inclined at low angles to {01$\bar{1}$2}. Careful scanning of many grains fails to reveal evidence of displacement of {01$\bar{1}$2} lamellae where intersected by L_1, such as might be expected on this second hypothesis. Moreover, observations on deformed single crystals strongly support the first alternative.

Anomalous Lamellae L_2

These lamellae superficially resemble {01$\bar{1}$2} structures (Pl. 1C, D) but cut [0001] somewhat more acutely, so that the angle between the pole of L_2 and [0001] is between 30° and 40° instead of 26¼°. Unlike L_1 lamellae they are never associated with acutely intersecting {01$\bar{1}$2} structures, and moreover they invariably occur in grains strongly twinned on one or more sets of {01$\bar{1}$2} planes.

The nature of L_2 lamellae may be demonstrated most satisfactorily in strongly twinned grains of specimens deformed at 300°C by compression parallel or by extension normal to the foliation. In any such grain two crystal lattices, mutually related by twinning on {01$\bar{1}$2}, are about equally developed. Usually one lattice predominates in one portion (perhaps the central zone), and the second lattice in another of the grain in question; or one may predominate throughout the whole grain. The two *c* axes tend to lie respectively subparallel and at a high angle to the initial foliation. From our knowledge of the state of preferred orientation of calcite axes prior to deformation it is safe to conclude that in 9 cases out of 10 the *c* axis inclined to the foliation at a high angle represents the original lattice. We shall refer to the second lattice, with *c* axis subparallel to the foliation, as the twinned lattice.

TABLE 1.—L_1 LAMELLAE IN RELATION TO RESOLVED SHEAR STRESS

Grain	Resolved shear stress coefficient		
	e_1	e_2	e_3
1	.32*	.43	.43
2	.15*	.31	.49
3	.10	.25*	.46
4	.24	.21*	.50
5	.20*	.35	.49
6	.41*	.30	.45
7	.12*	.24*	.47
8	.26*	.21	.50
9	.50*	.25	.25
10	.35*	.27	.49

L_1 lamellae are associated with {01$\bar{1}$2} lamellae marked*. {01$\bar{1}$2} lamellae are designated e_1, e_2, and e_3 in order of decreasing spacing index. In all cases the resolved shear stresses on e_1, e_2, and e_3 are in the sense opposed to twin gliding.

In grains such as the above, a number of generalizations hold without exception:

(1) The most prominent {01$\bar{1}$2} lamellae, e_1, are those on which twinning has occurred. They are common to both lattices; and, within limits of error of measurement, their pole is 26° from both *c* axes.

(2) Poles of lamellae L_2 lie 30°–40° from the *c* axis of the original lattice; and the angle between respective poles of L_2 and of twin plane e_1 is 50°–65°. These angles are greatest in those parts of the grain where twinning has proceeded furthest. The lamellae L_2 consequently are curved in grains that are unevenly twinned on e_1.

(3) Where parts of a grain are virtually untwinned so that the original lattice is locally intact, individual L_2 lamellae of the strongly

PLATE 2.—LAMELLAE IN EXPERIMENTALLY DEFORMED YULE MARBLE

(Polarized Light)

(a) Diagonal lamellae L_3 in grain almost completely twinned on vertical {01$\bar{1}$2}. × 132. (b) Sharp lamellae {02$\bar{2}$1} (horizontal) associated with dense sets of {01$\bar{1}$2} lamellae with minor twinning, and lamellae L_1 (inclined NW-SE). × 154. (c) Cleavage {10$\bar{1}$1} in top right portion of principal grain (inclined WNW-ESE). Horizontal structures are nontwinned lamellae {01$\bar{1}$2} inclined to plane of photograph. × 125. (d) Lamellae {10$\bar{1}$1}, vertical × 133.

twinned areas are continuous with corresponding $\{01\bar{1}2\}$ lamellae of adjoining untwinned areas (Pl 1C).

(4) L_2 lamellae, though seldom numerous, are conspicuous because they appear thick and dark. Their boundaries, under high magnification, may appear finely serrated rather than strictly planar. These characteristics impart a distinctive appearance which enables L_2 lamellae to be recognized at a glance by an experienced observer. In some cases they are broad enough for differences in extinction and internal structure, as compared with those of the host crystal, to be clearly recognizable. They then have the appearance of twins; but lattices within L_2, insofar as can be determined from internal cleavages and partings and from extinction behavior, cannot be related rationally to the lattice of the host.

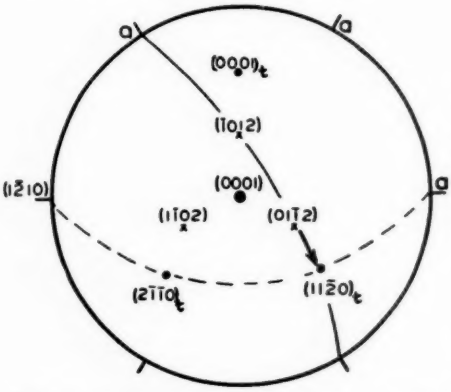


FIGURE 2.—EQUAL-AREA PROJECTION (upper Hemisphere) SHOWING DEVELOPMENT OF L_2 LAMELLAE IN CALCITE

As the host crystal deforms by twin gliding on $(\bar{1}012)$, the pole of L_2 moves along the arc $(01\bar{1}2) \rightarrow (11\bar{2}0)_t$ as indicated by the arrow. Symbols with subscript t refer to twinned lattice.

All the above characteristics can be explained if it is assumed that L_2 lamellae are relict $\{01\bar{1}2\}$ twin bands present in grains of the original undeformed fabric. If a grain initially containing a few $(01\bar{1}2)$ twin lamellae were subjected to stress favoring twinning on $(\bar{1}012)$, then as twin gliding on $(\bar{1}012)$ proceeded, the bands $(01\bar{1}2)$ $(=L_2)$ would rotate through the deforming lattice. They would retain their own internal lattices and could adjust themselves internally to changing stress by local gliding. This could account for the dark color, serrated outlines, and in some cases internal local partings (glide planes or cleavages) shown by L_2 lamellae. The direction and sense of twin gliding on $(1\bar{1}02)$ or $(\bar{1}012)$ are such that the angle between $\{0001\}$ and L_2 [originally $(01\bar{1}2)$] must increase from 26° as twinning proceeds. The locus of the pole of L_2 as it is rotated through the enclosing crystal (shown by the thickened arc and arrow in Fig. 2) must lie on the great circle containing poles of $(01\bar{1}2)$ and $(\bar{1}012)$, for the axis of rotation of the lamella $(01\bar{1}2)$ will be its intersection with the $(\bar{1}012)$ plane of twin gliding. (*Cf.* Figure 3.)

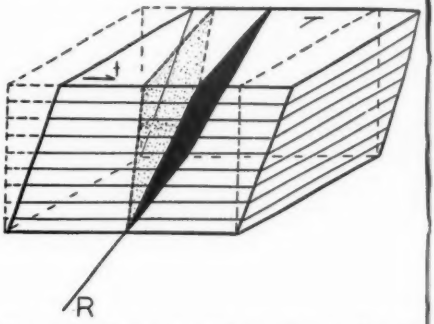


FIGURE 3.—ROTATION OF LAMELLAE BY GLIDING

The body outlined in broken lines is deformed to that shown in full lines by homogeneous gliding on planes T in the direction t in the sense indicated by the arrow. The stippled plane is simultaneously rotated about axis R to the position shown in black.

Anomalous Lamellae L_3

Lamellae designated L_3 approximate, within limits of error of measurement, prismatic planes $\{11\bar{2}0\}$ and so are parallel to the [0001] axis of the dominant lattice of the grain in which they occur. They appear only in grains or parts of grains that are almost completely twinned. This must be the actual state of the many seemingly slightly twinned grains whose [0001] axes are subparallel to the foliation, in specimens so deformed as to favor twin gliding in most grains. In general appearance L_3 lamellae are identical with L_2. Indeed, where there are

partially and completely twinned areas within one grain, L_2 lamellae in the former curve and pass into corresponding L_3 lamellae in the latter. Identical origins for both structures can be demonstrated in such cases.

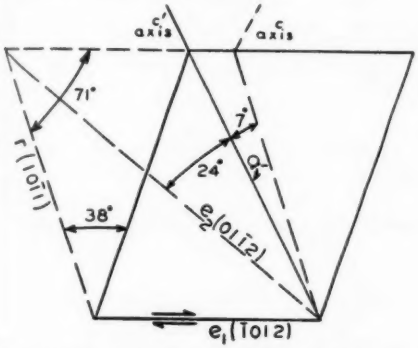


FIGURE 4.—ROTATION OF e_2 LAMELLA BY TWINNING ON e_1 IN CALCITE

The plane of the diagram is perpendicular to r (10$\bar{1}$1) and e_1 ($\bar{1}$012) of the lattice before twinning (broken lines) and after twinning on e_1 (solid lines). The lamella e_2 of the initial lattice is rotated by twinning on e_1 to coincide with (11$\bar{2}$0) = a' of the twinned lattice; and the traces of these two planes on the plane of the diagram intersect at 24°.

We suggest therefore that there is no fundamental difference between L_2 and L_3 lamellae. Both are rotated relict {01$\bar{1}$2} twin lamellae inherited from the original lattice. As twinning on another set of {01$\bar{1}$2} planes is set in motion by experimental deformation, the L_2 lamellae rotate bodily through the deforming lattice. When twinning is nearing completion the angle between the pole of L_2 and [0001] of the original lattice approaches 47°, and at the same time the lamellae L_2 become parallel to [0001] of the now-dominant twinned lattice. This latter direction is the [0001] axis normally measured in an almost completely twinned grain; so that lamellae L_3 are normally recorded as being parallel to the [0001] axis of the grain in which they occur.

In support of the above interpretation four observations are noted:

(1) As shown in Figures 4 and 5, twin gliding on a particular {01$\bar{1}$2} plane of the *original* lattice—*e.g.* ($\bar{1}$012)—would rotate a previously existing twin lamella (01$\bar{1}$2) until it coincides with (11$\bar{2}$0) of the *twinned* lattice. Thus a lamella (01$\bar{1}$2) of the original grain first assumes the character of L_2 in the original lattice, and as rotation by twinning proceeds it will ultimately be identified as L_3, = {11$\bar{2}$0}, of the twinned lattice.

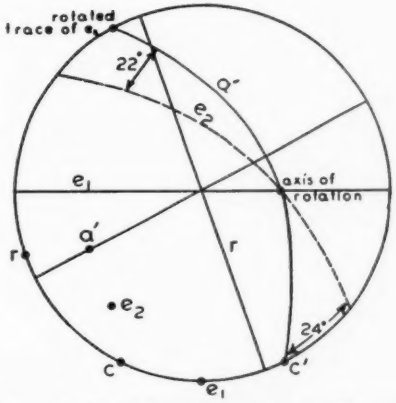


FIGURE 5.—EQUAL-AREA PROJECTION FOR CALCITE

Rotation of e_2 lamellae through 22° to coincide with (11$\bar{2}$0) = a' in the twinned lattice, as a result of twinning on e_1. Axes c and c' refer to initial and twinned lattices respectively. Lamella poles are shown as solid circles.

(2) The angle between observed lamellae L_3 and the active twin plane ($\bar{1}$012) is approximately 68°. Of the three {11$\bar{2}$0} planes of the twinned lattice two are inclined at 68°, and the third at 90° to the twin plane ($\bar{1}$012). In the many L_3 lamellae measured by us, angles approximating 68° are the invariable rule; angles approaching 90° have never been recorded.

(3) Random samples of grains with conspicuous L_3 lamellae were selected in each of two specimens. Resolved shear-stress coefficients were determined for all three {01$\bar{1}$2} planes of the original lattice of each grain on two alternative assumptions. If it is first assumed that the original lattice is greatly dominant, and that twinning on the most prominent {01$\bar{1}$2} lamellae, e_1, is just commencing, the coefficient of resolved shear stress on e_1 is invariably high, but the sense of shear is opposite to that which is effective in twin gliding. However, if it is assumed that the grains are almost completely twinned on e_1, then the resolved shear stress in every case is high and in the sense appropriate for twin gliding. Moreover, on the same latter

assumption, the resolved shear stresses on the other two {01$\bar{1}$2} planes of the original lattice are typically low or act in the sense opposite to that favoring twinning. In every case the position of L_3 in relation to the dominant lattice in which it occurs is such as would be expected on the hypothesis of rotation of L_3 due to substantially complete twinning on e_1.

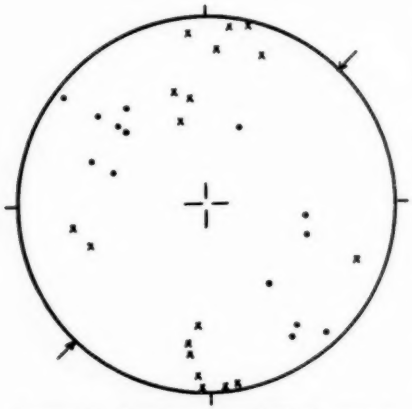


FIGURE 6.—ORIENTATION OF {02$\bar{2}$1} LAMELLAE

Poles of shear lamellae (crosses) and tension cracks (dots) parallel to {0221} in Specimen 282, deformed by compression (arrows) at 45° to foliation (N-S).

(4) L_3 lamellae commonly show discontinuities (*e.g.*, Pl. 2A) which could well be due to partial disruption of passively rotated structures.

PLANAR STRUCTURES PARALLEL TO {10$\bar{1}$1}

With a little experience it is possible to distinguish at a glance between {10$\bar{1}$1} cleavages and {01$\bar{1}$2} lamellae. The former (Pl. 2C) typically appear as fainter less continuous lines traversing the section, and in some cases are defined by planar discontinuity of the grain where it has opened along cleavage cracks during preparation of the rock section. In many specimens of experimentally deformed marble some grains show unusually conspicuous {10$\bar{1}$1} "lamellae" somewhat resembling nontwinned lamellae {01$\bar{1}$2} (Pl. 2D). Under high magnification these {10$\bar{1}$1} "lamellae" may be resolved into sheaves of closely spaced individual cleavages or partings. In a few cases they may possibly represent very thin twin lamellae, but this is difficult to demonstrate beyond doubt since individuals twinned on {10$\bar{1}$1} would extinguish almost simultaneously between crossed nicols.

In some specimens at least, there is distinct preferred orientation of {10$\bar{1}$1} "lamellae" in planes of high resolved shear stress.

LAMELLAE {02$\bar{2}$1}

Lamellae parallel to {02$\bar{2}$1} are not uncommon in calcite of marble deformed at 20°C. They are relatively rare in material deformed at 150°C and at 300°C. Two types of lamella may be distinguished by an experienced observer:

(1) Swarms of closely spaced very sharp thin lines (Pl. 2B), conforming exactly to the position of {02$\bar{2}$1} in the lattice. Such lamellae could well be products of crystal gliding in a direction normal to the edge (02$\bar{2}$1):(01$\bar{1}$0), which is believed to give rise to lamellar {02$\bar{2}$1} twinning in dolomite (Fairbairn, 1949, p. 28). The resolved shear stress coefficient computed for this direction, in the sense appropriate for twin gliding,[2] invariably is high in the case of visible {02$\bar{2}$1} lamellae of this first type in deformed marble. (*Cf.* Part III, p. 901.)

(2) Groups of few dark, discontinuous, somewhat wavy partings closely approximating {02$\bar{2}$1}. These invariably appear parallel to surfaces of low shear stress but are almost perpendicular to the principal axis of extension of the specimen. They are in fact tension cracks.

Orientation of both types of {02$\bar{2}$1} lamellae in relation to applied stress is illustrated in Figure 6. A consistent characteristic of {02$\bar{2}$1} lamellae is their appearance only in grains unfavorably oriented for twinning on {01$\bar{1}$2}.

PARTING ON {10$\bar{1}$0}

Somewhat irregular cracks approaching parallelism to {10$\bar{1}$0} were noted in rather rare grains in specimens deformed at 20° and 150°C. These structures are almost certainly due to

[2] The sense of twin gliding on {02$\bar{2}$1} in dolomite is such that upper layers of the lattice are displaced downward from the upper end of the *c* axis. This is the opposite of the sense of {01$\bar{1}$2} twin gliding in calcite.

shear since they show a marked tendency to be oriented parallel to planes of high resolved shear stress coefficient. Mrs. Knopf records {10$\bar{1}$0} lamellae as occurring much more frequently than is consistent with our observations. She has probably included the more conspicuous and commonly developed structures which we have termed L_3 lamellae.

TABLE 2.—SYNOPSIS OF TYPES OF LAMELLAE

Type	Angle from lamella pole		Appearance	Dynamic significance
	to c axis	to pole of {01$\bar{1}$2}		
{01$\bar{1}$2} twinned	26°	45°	Sharply defined parallel bands with difference in extinction	Stresses most effective in twinning are inclined at 45° to twin plane: either tension at 19° to [0001] or compression at 71° to [0001]
{01$\bar{1}$2} nontwinned	26°	45°	Continuous parallel dark lines	Stress most effective is compression at high angle to {01$\bar{1}$2} plane in question
L_1	Typically 15°–21°	Typically 5°–11°	Continuous sharp lines inclined acutely to visible nontwinned {01$\bar{1}$2}	Compression at high angle to L_1
L_2	30°–40°	50°–65° to pole of {01$\bar{1}$2} twin	Resemble nontwinned {01$\bar{1}$2} lamellae, but thicker, darker, and with somewhat serrated boundaries	Indicates strong twinning on principal {01$\bar{1}$2} lamellae at 50°–65° to L_2
L_3	90°	68° to pole of {01$\bar{1}$2} twin	Resemble L_2 and may pass into L_2 lamellae in partially twinned areas of grain	The lattice with c axis parallel to L_3 is the product of almost complete twinning
{10$\bar{1}$1}	44½°	38°; 71° (cozonal with {0001})	Dark widely spaced continuous lines	In some cases are planes of high shear stress
{02$\bar{2}$1}*	63°	78½°; 37° (cozonal with {0001})	Occur in nontwinned crystals: (a) Sharp parallel thin lines, closely spaced (b) Somewhat undulating dark thicker lines	(a) Planes of high shear stress at 45° to compression or tension axis (b) Partings normal to axis of tension
{10$\bar{1}$0}	80°–90°	64°	Somewhat curved widely spaced cracks; not strictly parallel	Partings parallel to planes of high shear stress

* Common only in specimens deformed at room temperatures.

CONCLUSION

The various types of lamellae developed in calcite of marble deformed at temperatures ranging up to 300°C are listed in Table 2, together with criteria for their recognition, and the stress conditions which favor their development. Recognition of comparable lamellae in marble that has been deformed without notable recrystallization under natural conditions should make dynamic interpretation of such natural marble fabrics possible. Preliminary attempts in this direction, confined so far to interpretation of {01$\bar{1}$2} lamellae, are yielding promising results (Turner, 1953; McIntyre and Turner, 1953).

REFERENCES CITED

Adams, F. D., and Nicolson, J. T., 1901, An experimental investigation into the flow of marble: Royal Soc. London Philos. Trans., ser. A, v. 195, p. 363–401.

Fairbairn, H. W., 1949, Structural petrology of deformed rocks: Cambridge, Mass., Addison Wesley, 344 p.

Griggs, D., 1936, Deformation of rocks under high confining pressure: Jour. Geology, v. 44, p. 541–577.

Griggs, D., and Miller, W. B., 1951, Deformation of Yule marble, Part I: Geol. Soc. America Bull., v. 62, p. 853–906.

Griggs, D., Turner, F. J., Borg, I., and Sosoka, J., 1951, Deformation of Yule marble, Part III: Geol. Soc. America Bull., v. 62, p. 1385–1406.

——, 1953, Deformation of Yule marble, Part V: Geol. Soc. America Bull., v. 64, p. 1327–1342.

Handin, J. W., and Griggs, D., 1951, Deformation of Yule marble, Part II: Geol. Soc. America Bull., v. 62, p. 863–886.

Knopf, E. B., 1949, Fabric changes in Yule marble after deformation in compression: Am. Jour. Sci., v. 247, p. 433–461, 537–569.

McIntyre, D. B., and Turner, F. J., 1953, Petrofabric analysis of marbles from Mid-Strathspey and Strathavon: Geol. Mag., v. 90, p. 225–240.

Sander, B., 1950, Einführung in die Gefügekunde der geologischen Körper, *II:* Springer, Vienna, 399 p.

Turner, F. J., 1949, Preferred orientation of calcite in Yule marble: Am. Jour. Sci., v. 247, p. 593–621.

——, 1953, Nature and dynamic interpretation of deformation lamellae in calcite of three marbles: Am. Jour. Sci., v. 251, p. 276–298.

Turner, F. J., and Ch'ih, C. S., 1951, Deformation of Yule marble, Part III: Geol. Soc. America Bull., v. 62, p. 887–906.

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STRATIGRAPHY AND PETROLOGY OF THE TASCOTAL MESA QUADRANGLE, TEXAS

By Ralph L. Erickson

Abstract

The Tertiary Buck Hill volcanic series, about 4000 feet thick, covers most of the Tascotal Mesa quadrangle in Presidio and Brewster counties, Texas. The regional dip in the northern part of the quadrangle is 2°–4° SW., and differential erosion has developed three prominent levels. Green Valley in the northeastern part is underlain by Pruett and Duff beds. Rising approximately 800 feet above the level of Green Valley is Bandera Mesa capped by the resistant Mitchell Mesa tuff flow. Tascotal Mesa rises 800 feet above Bandera Mesa and is capped by flows of the Rawls basalt that form a dip slope to the western boundary of the quadrangle.

The southern third of the quadrangle, set off from the northern part by east-west faults, is characterized by rugged topography developed chiefly on the Rawls basalt flows. In the southeast corner Cretaceous strata that dip to the north off the Solitario uplift form hogbacks and cuestas.

The Solitario uplift, initiated in late Cretaceous time, continued during the deposition of the Tertiary volcanic series which thins and wedges against the dome. Uplift probably was not at a uniform rate; a period of marked uplift accompanied or followed shortly the intrusion of riebeckite soda rhyolite which forms numerous hills in the southeast part of the area.

The intrusives contributed abundant large boulders to the conglomerate of the upper beds of the Tascotal formation that lap on the slopes of the rhyolite hills. Boulders of Caballos novaculite and of black chert suggestive of the Maravillas formation indicate an appreciable contribution from the folded Paleozoic rocks that were uncovered by erosion of the Solitario complex.

Late Tertiary orogenic movements resulted in compressive forces acting on the structurally downwarped Marfa basin in which the Buck Hill volcanic series accumulated. The volcanic series was folded in a broad anticlinal structure, and the southwestward-dipping beds in the northern part of the quadrangle are the west limb of this large structure. Uplift was accompanied or followed by normal faulting.

The igneous rocks of the Tascotal Mesa quadrangle are alkalic. Analcime and soda-rich pyroxene and amphibole are characteristic. Both extrusive and intrusive rocks show a silica range from 46 to 73 per cent.

Quaternary deposits are related to the physiographic history of the region; gravel-capped pediments in Green Valley are now being dissected.

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Introduction

Location

The Tascotal Mesa quadrangle is in southeastern Presidio and southwestern Brewster counties, Trans-Pecos Texas (Fig. 1). Bandera Mesa and Tascotal Mesa are reached most easily from Marfa, 50 miles north, by the Marfa-Lajitas road which traverses the quadrangle from north to south. Green Valley in the northeastern part of the area is most easily reached from Marfa by the 02 Ranch road in Paradise Valley; an alternate route is from Alpine by the Terlingua highway and the 02 Ranch road.

Scope of Work

The geologic work in the Tascotal Mesa quadrangle is part of a project of geologic studies in southern Trans-Pecos Texas conducted by the Bureau of Economic Geology, The University of Texas. Workers in this region include Goldich and Elms (1949) in the Buck Hill quadrangle, Goldich and Seward (1948) and Goldich, Elms, and Seward (1949) in the Jordan Gap quadrangle, R. R. Bloomer (Unpublished manuscript, 1949) in the Christmas and Rosillos Mountains, Moon (1953) in the Agua Fria quadrangle, R. W. Graves (Unpublished manuscript, 1949) in the Hood Spring quadrangle, G. M. Stafford (Open-file manuscript, 1952) in the Nine Point Mesa quadrangle, W. N. McAnulty (Unpublished manuscript, 1953) in the Cathedral Mountain quadrangle, and C. C. Rix (Unpublished manuscript, 1953) in the Chinati Mountains. Lonsdale (1940) studied and mapped the igneous rocks of the Terlingua-Solitario region, and with Ross A. Maxwell is preparing a report on the geology of the Big Bend National Park.

This investigation is primarily concerned with a thick succession of volcanic tuff and and related sediments with intercalated lava flows which Goldich and Elms (1949, p. 1143) named the Buck Hill volcanic series. Six months was spent in the field during the summer of 1949 and the spring of 1950. Mapping was done on aerial photographs and later transferred to the U. S. Geological Survey topo-

graphic quadrangle map (ed., 1944; surveyed in co-operation with the War Department).

Acknowledgments

The field work and a large part of the cost of the chemical analyses were financed by the Bureau of Economic Geology, The University of Texas. The writer is indebted to Dr. John T. Lonsdale, Director, for this support and for his personal interest in all phases of the work. The laboratory work was done in the Department of Geology and Mineralogy, and the chemical work in the Rock Analysis Laboratory of the University of Minnesota. The writer is indebted to Dr. S. S. Goldich for suggestions and useful criticism. Darwin Cedarleaf assisted during the field season in 1949, and Conrad Appledorn in 1950. Robert B. Haynie was helpful in the identification of the Cretaceous formations. The ranchers of the area were generous in their co-operation.

Climate and Vegetation

The Tascotal Mesa quadrangle is in the driest climatic province of Texas. Daytime temperatures often reach 100°F. in the summer months, but the relative humidity is usually below 10 per cent, and the nights are cool. The rains come chiefly in July and August when short thundershowers, many accompanied by violent winds, occur almost daily; 2–3 inches of rain may fall within a few hours.

Various forms of cacti, yuccas, and other hardy plants are common and show a close relationship to rock type and topography. Ocotillo grows on weathered flats and gentle slopes, particularly on the flows. Tuff outcrops are commonly covered with the spiny lechu-

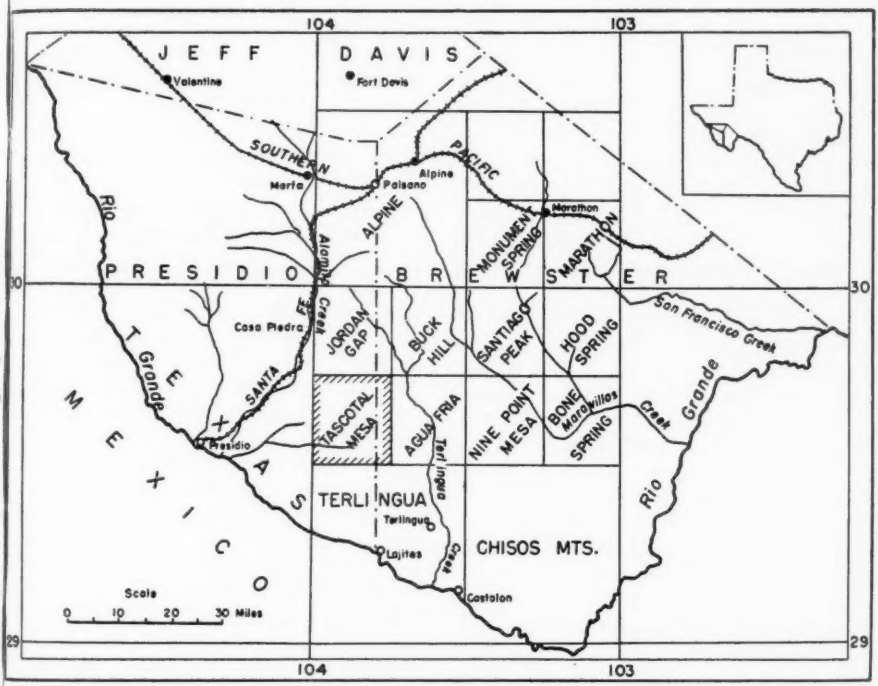

FIGURE 1.—INDEX MAP OF PART OF TRANS-PECOS TEXAS

Showing Tascotal Mesa and adjacent quadrangles mapped as part of the West Texas project of the Bureau of Economic Geology, The University of Texas: Buck Hill, Goldich and Elms (1949); Jordan Gap, Goldich and Seward (1948); Agua Fria, Moon (1953).

guilla. Sagebrush and creosote bush are found on the valley flats, and catclaw grows near the waterways. Bunch grass is the principal natural forage of the livestock and is abundant on mesa tops if there is enough rain.

Topographic Development

The topography in the Tascotal Mesa quadrangle was largely developed by differential erosion. Rock types and structure are the controlling factors in the development of mesas (Pls. 4, 5) in the northern two-thirds of the quadrangle and of rugged hills and steep valleys in the southern third.

Green Valley, which occupies the northeastern part of the quadrangle, has an altitude of 3600–3700 feet. Igneous intrusives form Needle Peak (Pl. 4, fig. 2) and The Dike, two prominent landmarks on this flat lowland. Green Valley is drained by creeks that flow eastward and join Terlingua Creek in Agua Fria quadrangle.

Facing Green Valley is the 700- to 800-foot scarp of Bandera Mesa (Pl. 4, fig. 1), capped by the resistant Mitchell Mesa rhyolitic tuff flow that dips 2° SW. Small, intermittent consequent streams follow the dip slope and are captured by subsequent streams which flow north and south and divert the drainage into South Canyon. The scarp of the mesa has also been breached by streams which flow eastward to Green Valley and form Middle and North canyons.

San Jacinto Mountain in the northwest part of the quadrangle is a basaltic intrusive that rises 700 feet above the level of Bandera Mesa. La Viuda, 2½ miles southwest of San Jacinto, is a smaller intrusive.

The west-central part of the quadrangle is occupied by Tascotal Mesa which rises approximately 800 feet above Bandera Mesa to form the third major erosional level in the quadrangle. The mesa is capped by a thick series of basalt flows which are more resistant than the underlying Tascotal tuff but which weather more readily than the silicic tuff flow capping Bandera Mesa. The Rawls flows on Tascotal Mesa dip southwest, and the drainage is westward to Alamito Creek. A dendritic drainage pattern is developed on the Rawls basalt in contrast with the more linear drainage pattern on the rhyolitic tuff flow of Bandera Mesa, reflecting the different weathering qualities of the two caprocks. The highest point on the quadrangle, 5184 feet above sea level, is on the scarp of Tascotal Mesa south of the center of the quadrangle.

The porphyritic Rawls flows weather to irregular scarps and steep slopes, whereas the fine-grained nonporphyritic flows weather to thin slabs which generally from gentle slopes (Pl. 5, fig. 2). The alternation of porphyritic and nonporphyritic flows produces a rugged topography marked by many canyons, buttes, and peaks.

There is a great topographic contrast between the southern third and the rest of the quadrangle because the surface rocks in the southern part are chiefly Rawls basalt which have been displaced along the east-west Tascotal Mesa fault. Numerous small faults associated with igneous intrusive masses further complicate the structure and have influenced the topographic development. The major westward drainage is Torneros Creek, whose course is guided by the Tascotal Mesa fault. The eastward drainage through Alamo de Cesario Creek is guided by a secondary fault zone which trends roughly east-west and which is thought to be related to the larger Tascotal Mesa fault. The drainage divide between these two streams is approximately along the 103°50′ longitude line (Pl. 1).

The Alazan Hills are dissected, plateaulike remnants of flows capped by trachyandesite porphyry. Steep-walled canyons characterize the upper reaches of the creeks. La Mota Mountain near the western boundary of the quadrangle is a smaller plateaulike remnant with very steep slopes. On the west side of La Mota Mountain a large toreva block has been displaced vertically about 200 feet. Northwest of La Mota Mountain is a symmetrical domical uplift, the La Mota dome, which has been breached and eroded to a basin. Resistant plugs of microsyenite and gabbro form small spires in the basin.

The southeastern corner is the most rugged and inaccessible part of the quadrangle. The dip slope of Cretaceous rocks off the Solitario uplift (Pl. 2, fig. 1) has been complicated by

rhyolitic intrusives and by intricate faulting. Steep hills formed by the intrusives rise to altitudes approaching 4900 feet.

Pediments

Pediments slope gently to the east away from the receding scarps of Bandera and Tascotal mesas. The largest "rock cut" surface beveled the Duff and Pruett tuff in Green Valley and marks a former base level of erosion in the development of Green Valley. The pediment is now being dissected by renewed active downcutting in the area. The pediment remnants form prominent gravel-capped ridges in the northeastern part of the quadrangle which extend across Green Valley parallel to the present drainage system. These ridges are 30 to 40 feet high and are capped with 3 to 5 feet of unconsolidated gravels. Southward along the eastern border of the quadrangle, the pediment is being dissected by Point Draw and its tributaries. To the south, the rim of Alamo de Cesario canyon is capped with 15 feet of pediment gravels, but all traces of the pediment south of the canyon have been removed except for an isolated, narrow, three-pronged, gravel-capped ridge of tuff on the north side of Tascotal Mesa fault (Pl. 1). This ridge is level with the rim of Alamo de Cesario canyon.

Smaller isolated pediments are forming on Bandera Mesa south and northwest of Wire Gap by the recession of the scarp of Tascotal Mesa. The soft sand and tuff units below the caprock weather easily and promote sapping of the caprock so that large blocks give way and tumble to the bottom of the slope where they disintegrate to a gruss. The writer believes these pediments are the result primarily of weathering and retreat of the mesa scarp by marginal fragmentation, sapping, sheet wash, and rill wash. Lateral planation by streams probably has been a minor process.

Cretaceous System

General Statement

A thick section of Cretaceous rocks, principally limestone, is exposed in the southeast corner of the quadrangle for approximately 8 square miles. Along the south boundary of the quadrangle the Cretaceous strata form the northeastern flank of the Solitario uplift; dips are high (20°–30°), and hogbacks are developed in the thick-bedded limestones of the Comanche series (Pl. 2, fig. 1). North of the Solitario the regional dip is 10° or less, and cuestas result from the erosion of the Boquillas formation of the Gulf Series. (Pl. 2, fig. 2).

The pattern of the Cretaceous strata is complicated by faults and by numerous rhyolitic intrusives. The structural complications together with the rugged topography and general inaccessibility of this part of the area have limited the field studies of the Cretaceous formations, and few reliable observations of thicknesses could be made. It is estimated that the Cretaceous rocks exposed in the quadrangle exceed 2500 feet in thickness (Table 1). The formations, from youngest to oldest, differentiated on the geologic map (Pl. 1) are: Boquillas limestone, Buda limestone, Grayson clay, Devils River limestone, Glen Rose limestone.

Glen Rose Limestone

The single exposure of the Glen Rose limestone in the quadrangle, on the southern boundary, is best seen along the road that leads into the Solitario. In the inner rim of the Solitario basin the lowermost Cretaceous strata were measured by Scott (1939, p. 985) who found nearly 3000 feet for the Trinity section at Fresno Peak on the southwest side of the Solitario, approximately 5 miles south of the quadrangle boundary.

Only the upper part of the Glen Rose occurs in the Tascotal Mesa quadrangle. A 4-foot thickness of hard, reddish-pink, siliceous limestone, in beds averaging 8 inches thick, marks the top of the formation (Robert Haynie, personal communication, 1949). Hard, dark-gray, fine-grained limestone alternates with softer beds of marl and marly limestone. Some beds contain numerous *Orbitolina texana*; the uppermost of these is 30 feet below the ledge-forming, hard, siliceous limestone.

Weathering of the Glen Rose limestone is influenced by widespaced joints. Exposures are etched and corroded to rough irregular surfaces, and where the beds dip steeply a typical

assumption, the resolved shear stresses on the other two $\{01\bar{1}2\}$ planes of the original lattice are typically low or act in the sense opposite to that favoring twinning. In every case the position of L_3 in relation to the dominant lattice in

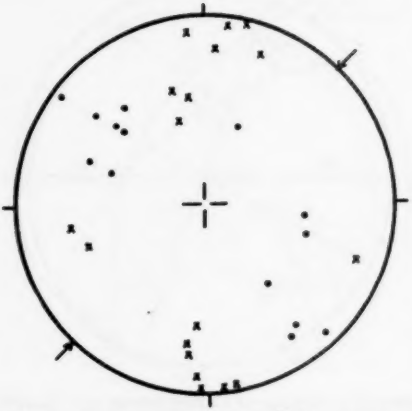

FIGURE 6.—ORIENTATION OF $\{02\bar{2}1\}$ LAMELLAE

Poles of shear lamellae (crosses) and tension cracks (dots) parallel to $\{02\bar{2}1\}$ in Specimen 282, deformed by compression (arrows) at 45° to foliation (N-S).

which it occurs is such as would be expected on the hypothesis of rotation of L_3 due to substantially complete twinning on e_1.

(4) L_3 lamellae commonly show discontinuities (*e.g.*, Pl. 2A) which could well be due to partial disruption of passively rotated structures.

PLANAR STRUCTURES PARALLEL TO $\{10\bar{1}1\}$

With a little experience it is possible to distinguish at a glance between $\{10\bar{1}1\}$ cleavages and $\{01\bar{1}2\}$ lamellae. The former (Pl. 2C) typically appear as fainter less continuous lines traversing the section, and in some cases are defined by planar discontinuity of the grain where it has opened along cleavage cracks during preparation of the rock section. In many specimens of experimentally deformed marble some grains show unusually conspicuous $\{10\bar{1}1\}$ "lamellae" somewhat resembling nontwinned lamellae $\{01\bar{1}2\}$ (Pl. 2D). Under high magnification these $\{10\bar{1}1\}$ "lamellae" may be resolved into sheaves of closely spaced individual cleavages or partings. In a few cases they may possibly represent very thin twin lamellae, but this is difficult to demonstrate beyond doubt since individuals twinned on $\{10\bar{1}1\}$ would extinguish almost simultaneously between crossed nicols.

In some specimens at least, there is distinct preferred orientation of $\{10\bar{1}1\}$ "lamellae" in planes of high resolved shear stress.

LAMELLAE $\{02\bar{2}1\}$

Lamellae parallel to $\{02\bar{2}1\}$ are not uncommon in calcite of marble deformed at 20°C. They are relatively rare in material deformed at 150°C and at 300°C. Two types of lamella may be distinguished by an experienced observer:

(1) Swarms of closely spaced very sharp thin lines (Pl. 2B), conforming exactly to the position of $\{02\bar{2}1\}$ in the lattice. Such lamellae could well be products of crystal gliding in a direction normal to the edge $(02\bar{2}1):(01\bar{1}0)$, which is believed to give rise to lamellar $\{02\bar{2}1\}$ twinning in dolomite (Fairbairn, 1949, p. 28). The resolved shear stress coefficient computed for this direction, in the sense appropriate for twin gliding,[2] invariably is high in the case of visible $\{02\bar{2}1\}$ lamellae of this first type in deformed marble. (*Cf.* Part III, p. 901.)

(2) Groups of few dark, discontinuous, somewhat wavy partings closely approximating $\{02\bar{2}1\}$. These invariably appear parallel to surfaces of low shear stress but are almost perpendicular to the principal axis of extension of the specimen. They are in fact tension cracks.

Orientation of both types of $\{02\bar{2}1\}$ lamellae in relation to applied stress is illustrated in Figure 6. A consistent characteristic of $\{02\bar{2}1\}$ lamellae is their appearance only in grains unfavorably oriented for twinning on $\{01\bar{1}2\}$.

PARTING ON $\{10\bar{1}0\}$

Somewhat irregular cracks approaching parallelism to $\{10\bar{1}0\}$ were noted in rather rare grains in specimens deformed at 20° and 150°C. These structures are almost certainly due to

[2] The sense of twin gliding on $\{02\bar{2}1\}$ in dolomite is such that upper layers of the lattice are displaced downward from the upper end of the c axis. This is the opposite of the sense of $\{01\bar{1}2\}$ twin gliding in calcite.

shear since they show a marked tendency to be oriented parallel to planes of high resolved shear stress coefficient. Mrs. Knopf records {10$\bar{1}$0} ment. Recognition of comparable lamellae in marble that has been deformed without notable recrystallization under natural conditions

TABLE 2.—SYNOPSIS OF TYPES OF LAMELLAE

Type	Angle from lamella pole		Appearance	Dynamic significance
	to *c* axis	to pole of {01$\bar{1}$2}		
{01$\bar{1}$2} twinned	26°	45°	Sharply defined parallel bands with difference in extinction	Stresses most effective in twinning are inclined at 45° to twin plane: either tension at 19° to [0001] or compression at 71° to [0001]
{01$\bar{1}$2} nontwinned	26°	45°	Continuous parallel dark lines	Stress most effective is compression at high angle to {01$\bar{1}$2} plane in question
L_1	Typically 15°–21°	Typically 5°–11°	Continuous sharp lines inclined acutely to visible nontwinned {01$\bar{1}$2}	Compression at high angle to L_1
L_2	30°–40°	50°–65° to pole of {01$\bar{1}$2} twin	Resemble nontwinned {01$\bar{1}$2} lamellae, but thicker, darker, and with somewhat serrated boundaries	Indicates strong twinning on principal {01$\bar{1}$2} lamellae at 50°–65° to L_2
L_3	90°	68° to pole of {01$\bar{1}$2} twin	Resemble L_2 and may pass into L_2 lamellae in partially twinned areas of grain	The lattice with *c* axis parallel to L_3 is the product of almost complete twinning
{10$\bar{1}$1}	44½°	38°; 71° (cozonal with {0001})	Dark widely spaced continuous lines	In some cases are planes of high shear stress
{02$\bar{2}$1}*	63°	78½°; 37° (cozonal with {0001})	Occur in nontwinned crystals: (a) Sharp parallel thin lines, closely spaced (b) Somewhat undulating dark thicker lines	(a) Planes of high shear stress at 45° to compression or tension axis (b) Partings normal to axis of tension
{10$\bar{1}$0}	80°–90°	64°	Somewhat curved widely spaced cracks; not strictly parallel	Partings parallel to planes of high shear stress

* Common only in specimens deformed at room temperatures.

lamellae as occurring much more frequently than is consistent with our observations. She has probably included the more conspicuous and commonly developed structures which we have termed L_3 lamellae.

CONCLUSION

The various types of lamellae developed in calcite of marble deformed at temperatures ranging up to 300°C are listed in Table 2, together with criteria for their recognition, and the stress conditions which favor their develop- should make dynamic interpretation of such natural marble fabrics possible. Preliminary attempts in this direction, confined so far to interpretation of {01$\bar{1}$2} lamellae, are yielding promising results (Turner, 1953; McIntyre and Turner, 1953).

REFERENCES CITED

Adams, F. D., and Nicolson, J. T., 1901, An experimental investigation into the flow of marble: Royal Soc. London Philos. Trans., ser. A, v. 195, p. 363–401.

Fairbairn, H. W., 1949, Structural petrology of deformed rocks: Cambridge, Mass., Addison Wesley, 344 p.

Griggs, D., 1936, Deformation of rocks under high confining pressure: Jour. Geology, v. 44, p. 541–577.

Griggs, D., and Miller, W. B., 1951, Deformation of Yule marble, Part I: Geol. Soc. America Bull., v. 62, p. 853–906.

Griggs, D., Turner, F. J., Borg, I., and Sosoka, J., 1951, Deformation of Yule marble, Part III: Geol. Soc. America Bull., v. 62, p. 1385–1406.

——, 1953, Deformation of Yule marble, Part V: Geol. Soc. America Bull., v. 64, p. 1327–1342.

Handin, J. W., and Griggs, D., 1951, Deformation of Yule marble, Part II: Geol. Soc. America Bull., v. 62, p. 863–886.

Knopf, E. B., 1949, Fabric changes in Yule marble after deformation in compression: Am. Jour. Sci., v. 247, p. 433–461, 537–569.

McIntyre, D. B., and Turner, F. J., 1953, Petrofabric analysis of marbles from Mid-Strathspey and Strathavon: Geol. Mag., v. 90, p. 225–240.

Sander, B., 1950, Einführung in die Gefügekunde der geologischen Körper, *II:* Springer, Vienna, 399 p.

Turner, F. J., 1949, Preferred orientation of calcite in Yule marble: Am. Jour. Sci., v. 247, p. 593–621.

——, 1953, Nature and dynamic interpretation of deformation lamellae in calcite of three marbles: Am. Jour. Sci., v. 251, p. 276–298.

Turner, F. J., and Ch'ih, C. S., 1951, Deformation of Yule marble, Part III: Geol. Soc. America Bull., v. 62, p. 887–906.

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Project Grant 561/50

EXPLANATION

Qal — Alluvium
Recent valley fill and stream alluvium.

Qg — Gravel
High-level and pediment gravels.

QUATERNARY

UNCONFORMITY

Tra / Trb / Trvb / Trbp — Rawls basalt
Interfingering basalt flows and volcanic breccia. (Trbp) trachybasalt porphyry; (Trb) dense basalt; (Trvb) volcanic basalt breccia; (Tra) trachyandesite.

Ttt — Tascotal formation
Light-colored rhyolitic tuff and sandy tuff in lower part; sandstone, tuffaceous sandstone and conglomerate in upper part; (.°.°.°.°.) massive conglomerate and fresh-water limestone facies in southeastern part of quadrangle.

Tmmr — Mitchell Mesa tuff-flow
Pink to gray rhyolitic tuff-flow

Tdt / Tpt — Pruett-Duff tuffs
(Tdt) *Duff formation; light-colored rhyolitic tuff with minor conglomerate and fresh-water limestone;*
(Tbf) *intercalated basalt flows in upper part.*
(Tpt) *Pruett formation; light-colored rhyolitic tuff with minor sandstone and conglomerate.*
Contact uncertain.

Miocene? / Oligocene / Eocene? — Buck Hill volcanic series

TERTIARY

UNCONFORMITY

Kbo — Boquillas formation
Alternating flaggy limestone and shale; calcareous shale predominates in upper part.

Kbu — Buda limestone
Massive, nodular limestone.

Kgy — Grayson clay
Clay-shale with sandy limestone layers.

Kdv — Devils River limestone
Massive limestone with abundant chert nodules.

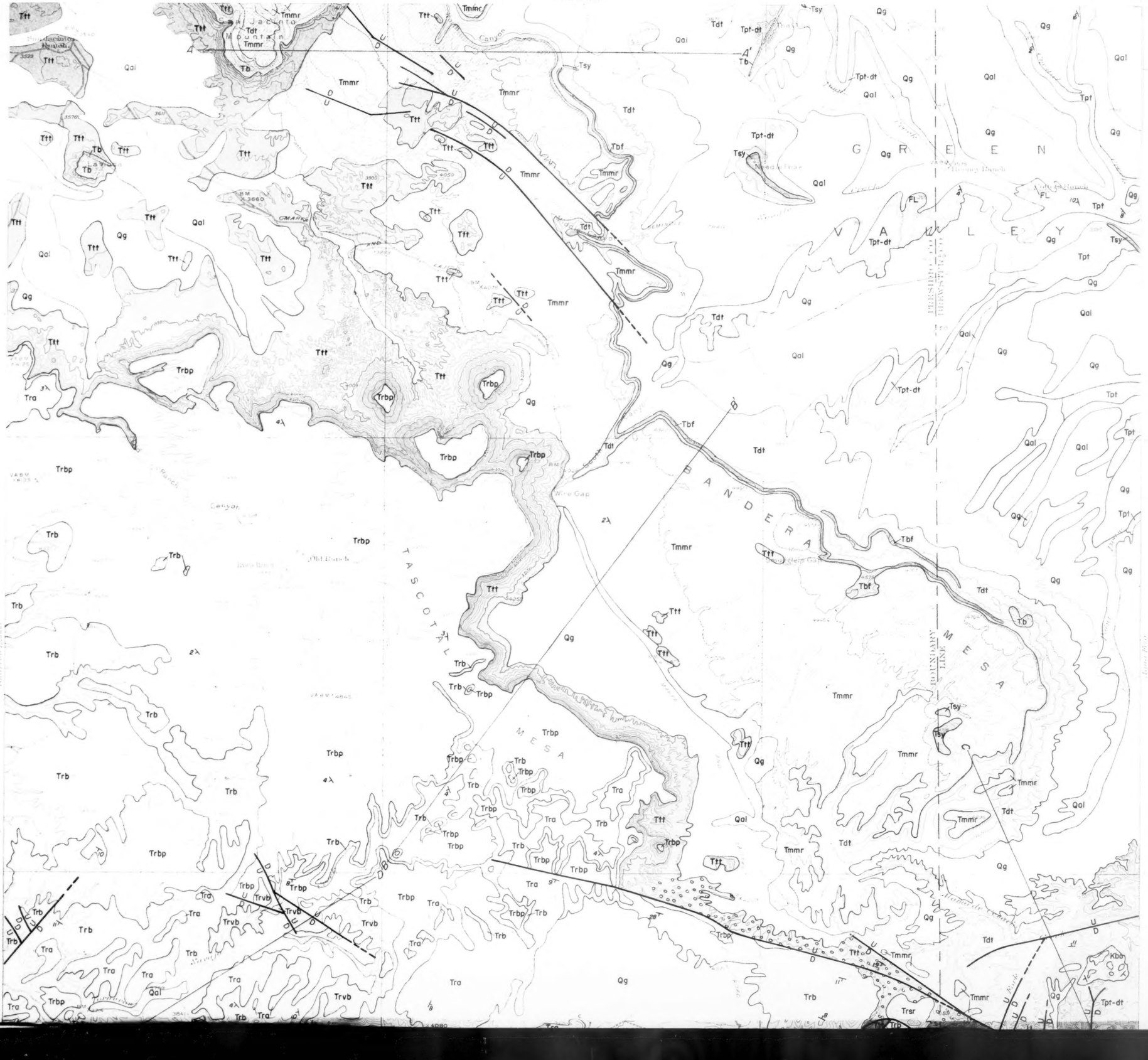
Kgr — Glen Rose limestone
Massive, dark gray limestone.

Gulf / Comanche

CRETACEOUS

INTRUSIVE IGNEOUS ROCKS

Tsy — Syenite
Alkalic microsyenite.


Ttt
Tmmr
Tdt
Tpt-dt
Tsy
Qg
Qal
Tbf
Tb
Trbp
Trvb
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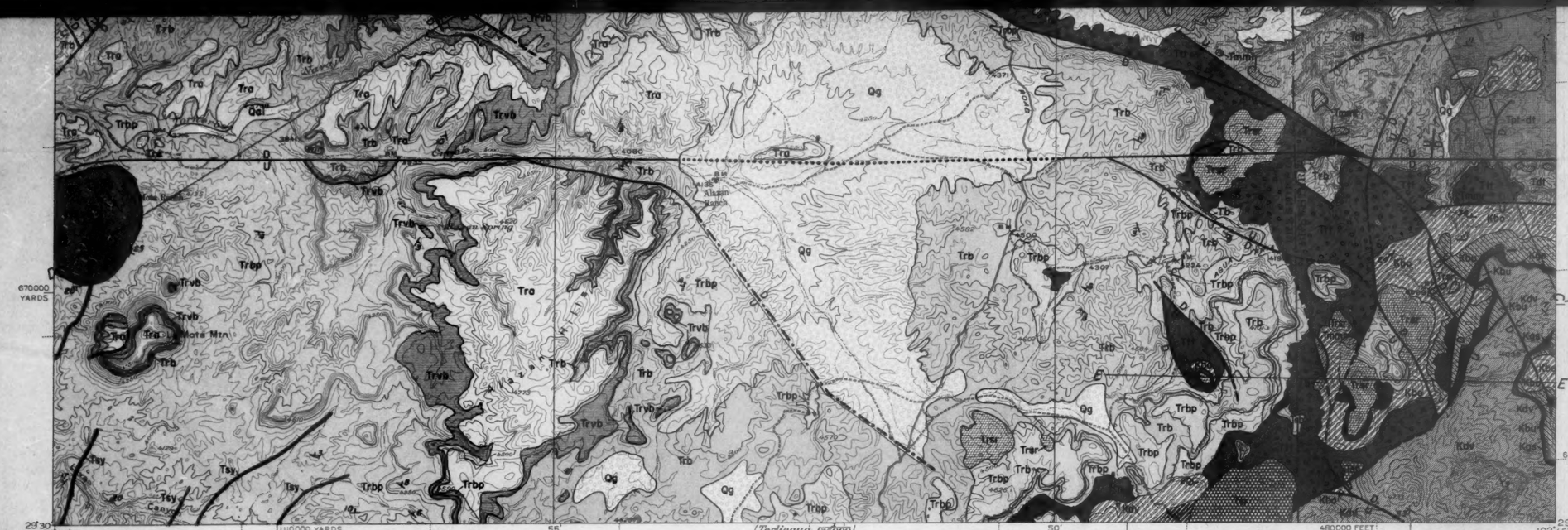
Tra
Kbo
Kbu
Kgs
Kgr
Kdv
Trsr
Mount San Jacinto
Indian Head
Wire Gap
Old Ranch
Cabezon Peak
Mitchell Mesa
Tascotal Mesa
Boundary Line
Bandera Valley
Green Valley
Hilltop Ranch
Cabezon Canyon
Cabezon Creek
Cabezon Ranch
Cabezon Spring
Cabezon Windmill
Cabezon Peak
Cabezon Mesa
Cabezon Valley



Topographic base by U. S. Geological Survey

Scale 1:62500

1 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1000 0 3000 6000 9000 12000 15000 18000 Feet

1 .5 0 1 2 3 4 5 Kilometers

Contour interval 50 feet

Datum is mean sea level

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1917

Geology surveyed by R. L. Erickson, 1949 and 1950

Glen Rose limestone

Massive, dark gray limestone.

INTRUSIVE IGNEOUS ROCKS

TERTIARY

Syenite

Alkalic microsyenite.

Gabbro

Analcime syenogabbro

Basalt

Soda rhyolite

Riebeckite soda rhyolite

U
D

Normal fault

U, *upthrown side;* D, *downthrown side; dashed where inferred; dotted where concealed by gravel.*

Fault

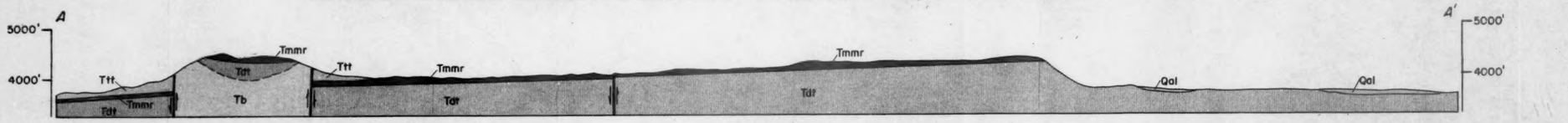
Downthrown side concealed by gravel; position marked by scarp.

Strike and dip of beds

FL

Fossil locality

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS



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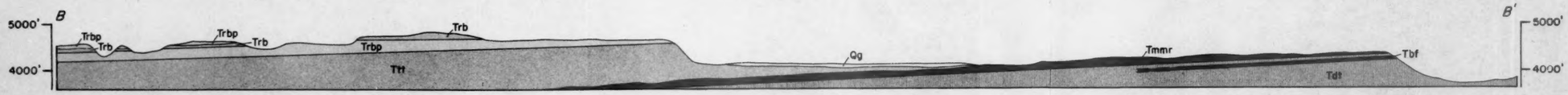

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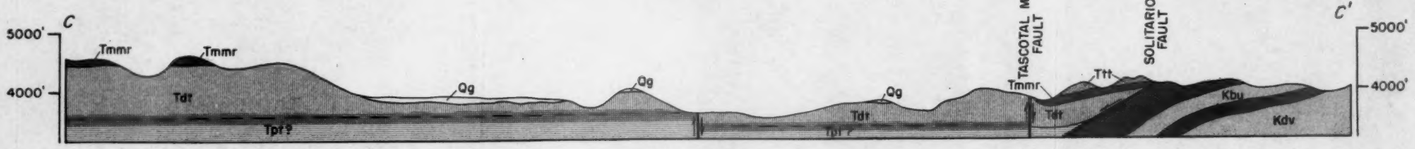

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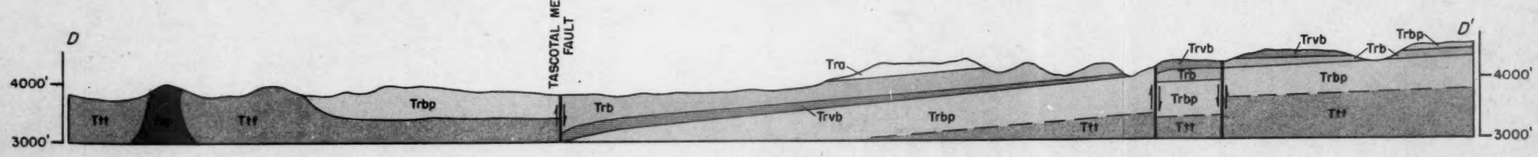

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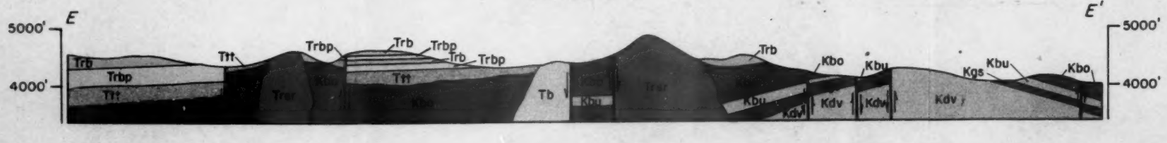

SECTION *E-E'*

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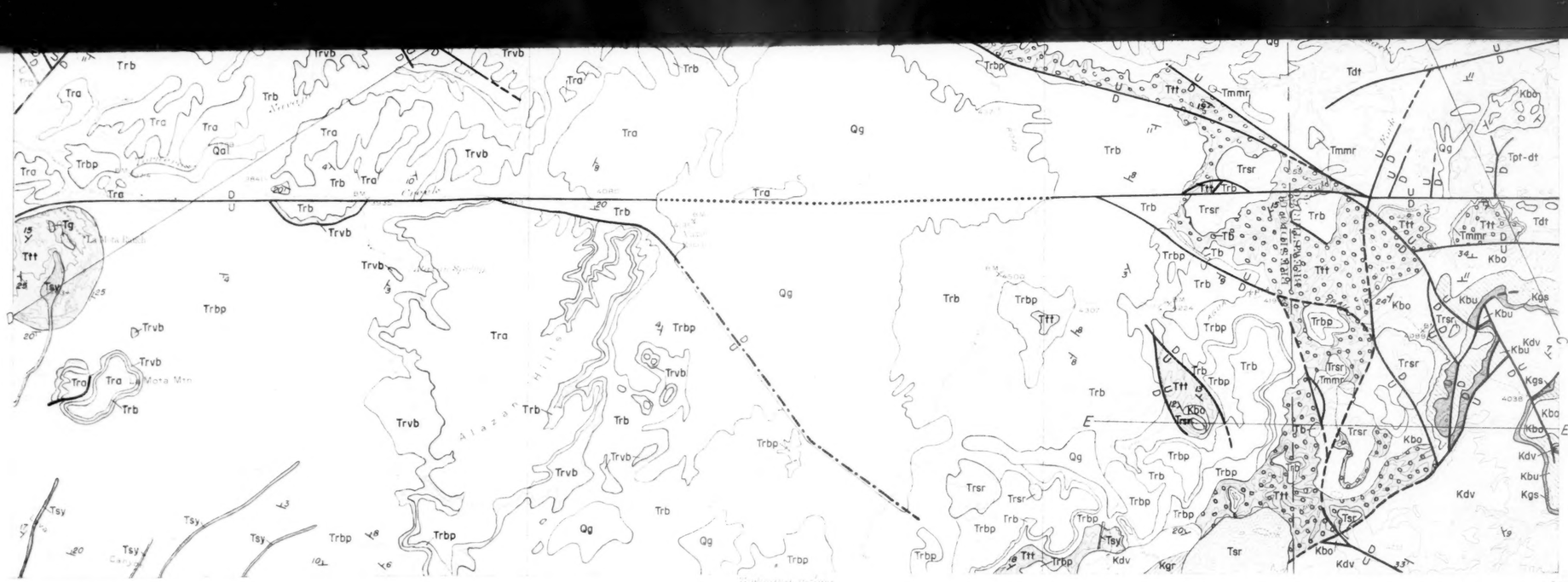
Scale of sections



Topographic base by U S Geological Survey

Geology surveyed by R L Erickson, 1949 and 1950

Scale as shown

Contour interval 50 feet

Datum is mean sea level

Glen Rose limestone

Massive, dark gray limestone.

INTRUSIVE IGNEOUS ROCKS

TERTIARY

Tsy

Syenite

Alkalic microsyenite.

Tg

Gabbro

Analcime syenogabbro

Tb

Basalt

Tsr

Soda rhyolite

Trsr

Riebeckite soda rhyolite

U
D

Normal fault

U, upthrown side; D, downthrown side; dashed where inferred; dotted where concealed by gravel.

Fault

Downthrown side concealed by gravel, position marked by scarp.

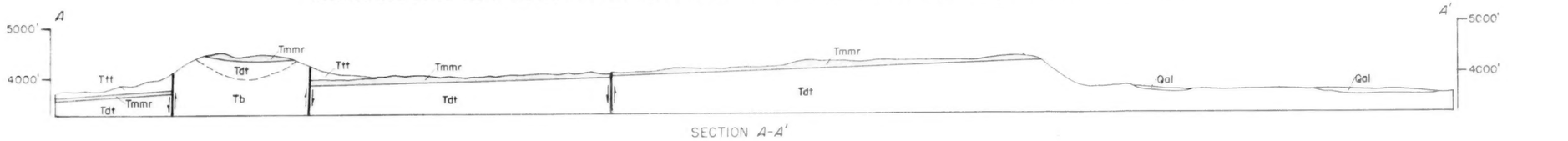
T2

Strike and dip of beds

FL

Fossil locality

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS



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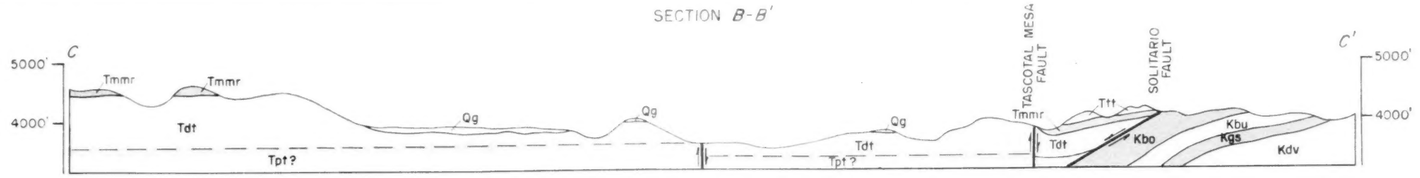

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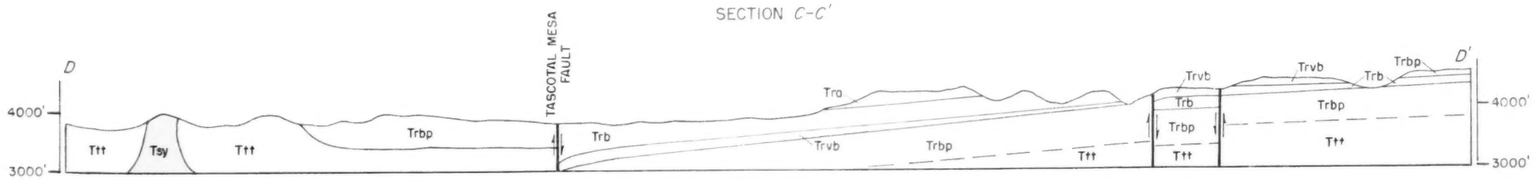

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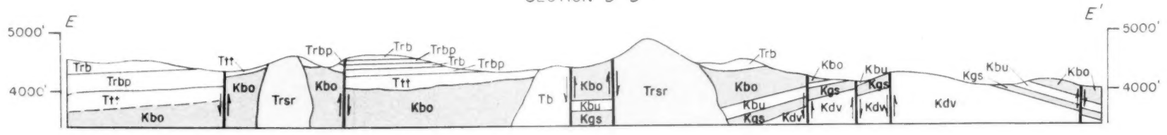

SECTION E-E'

1000 0 5000 10,000 FEET

Scale of sections

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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STRATIGRAPHY AND PETROLOGY OF THE TASCOTAL MESA QUADRANGLE, TEXAS

BY RALPH L. ERICKSON

ABSTRACT

The Tertiary Buck Hill volcanic series, about 4000 feet thick, covers most of the Tascotal Mesa quadrangle in Presidio and Brewster counties, Texas. The regional dip in the northern part of the quadrangle is 2°–4° SW., and differential erosion has developed three prominent levels. Green Valley in the northeastern part is underlain by Pruett and Duff beds. Rising approximately 800 feet above the level of Green Valley is Bandera Mesa capped by the resistant Mitchell Mesa tuff flow. Tascotal Mesa rises 800 feet above Bandera Mesa and is capped by flows of the Rawls basalt that form a dip slope to the western boundary of the quadrangle.

The southern third of the quadrangle, set off from the northern part by east-west faults, is characterized by rugged topography developed chiefly on the Rawls basalt flows. In the southeast corner Cretaceous strata that dip to the north off the Solitario uplift form hogbacks and cuestas.

The Solitario uplift, initiated in late Cretaceous time, continued during the deposition of the Tertiary volcanic series which thins and wedges against the dome. Uplift probably was not at a uniform rate; a period of marked uplift accompanied or followed shortly the intrusion of riebeckite soda rhyolite which forms numerous hills in the southeast part of the area.

The intrusives contributed abundant large boulders to the conglomerate of the upper beds of the Tascotal formation that lap on the slopes of the rhyolite hills. Boulders of Caballos novaculite and of black chert suggestive of the Maravillas formation indicate an appreciable contribution from the folded Paleozoic rocks that were uncovered by erosion of the Solitario complex.

Late Tertiary orogenic movements resulted in compressive forces acting on the structurally downwarped Marfa basin in which the Buck Hill volcanic series accumulated. The volcanic series was folded in a broad anticlinal structure, and the southwestward-dipping beds in the northern part of the quadrangle are the west limb of this large structure. Uplift was accompanied or followed by normal faulting.

The igneous rocks of the Tascotal Mesa quadrangle are alkalic. Analcime and soda-rich pyroxene and amphibole are characteristic. Both extrusive and intrusive rocks show a silica range from 46 to 73 per cent.

Quaternary deposits are related to the physiographic history of the region; gravel-capped pediments in Green Valley are now being dissected.

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INTRODUCTION

Location

The Tascotal Mesa quadrangle is in southeastern Presidio and southwestern Brewster counties, Trans-Pecos Texas (Fig. 1). Bandera Mesa and Tascotal Mesa are reached most easily from Marfa, 50 miles north, by the Marfa-Lajitas road which traverses the quadrangle from north to south. Green Valley in the northeastern part of the area is most easily reached from Marfa by the 02 Ranch road in Paradise Valley; an alternate route is from Alpine by the Terlingua highway and the 02 Ranch road.

Scope of Work

The geologic work in the Tascotal Mesa quadrangle is part of a project of geologic studies in southern Trans-Pecos Texas conducted by the Bureau of Economic Geology, The University of Texas. Workers in this region include Goldich and Elms (1949) in the Buck Hill quadrangle, Goldich and Seward (1948) and Goldich, Elms, and Seward (1949) in the Jordan Gap quadrangle, R. R. Bloomer (Unpublished manuscript, 1949) in the Christmas and Rosillos Mountains, Moon (1953) in the Agua Fria quadrangle, R. W. Graves (Unpublished manuscript, 1949) in the Hood Spring quadrangle, G. M. Stafford (Open-file manuscript, 1952) in the Nine Point Mesa quadrangle, W. N. McAnulty (Unpublished manuscript, 1953) in the Cathedral Mountain quadrangle, and C. C. Rix (Unpublished manuscript, 1953) in the Chinati Mountains. Lonsdale (1940) studied and mapped the igneous rocks of the Terlingua-Solitario region, and with Ross A. Maxwell is preparing a report on the geology of the Big Bend National Park.

This investigation is primarily concerned with a thick succession of volcanic tuff and and related sediments with intercalated lava flows which Goldich and Elms (1949, p. 1143) named the Buck Hill volcanic series. Six months was spent in the field during the summer of 1949 and the spring of 1950. Mapping was done on aerial photographs and later transferred to the U. S. Geological Survey topo-

graphic quadrangle map (ed., 1944; surveyed in co-operation with the War Department).

Acknowledgments

The field work and a large part of the cost of the chemical analyses were financed by the Bureau of Economic Geology, The University of Texas, and the writer is indebted to Dr. John T. Lonsdale, Director, for this support and for his personal interest in all phases of the work. The laboratory work was done in the Department of Geology and Mineralogy, and the chemical work in the Rock Analysis Laboratory of the University of Minnesota. The writer is indebted to Dr. S. S. Goldich for suggestions and useful criticism. Darwin Cedarleaf assisted during the field season in 1949, and Conrad Appledorn in 1950. Robert B. Haynie was helpful in the identification of the Cretaceous formations. The ranchers of the area were generous in their co-operation.

Climate and Vegetation

The Tascotal Mesa quadrangle is in the driest climatic province of Texas. Daytime temperatures often reach 100°F. in the summer months, but the relative humidity is usually below 10 per cent, and the nights are cool. The rains come chiefly in July and August when short thundershowers, many accompanied by violent winds, occur almost daily; 2–3 inches of rain may fall within a few hours.

Various forms of cacti, yuccas, and other hardy plants are common and show a close relationship to rock type and topography. Ocotillo grows on weathered flats and gentle slopes, particularly on the flows. Tuff outcrops are commonly covered with the spiny lechu-

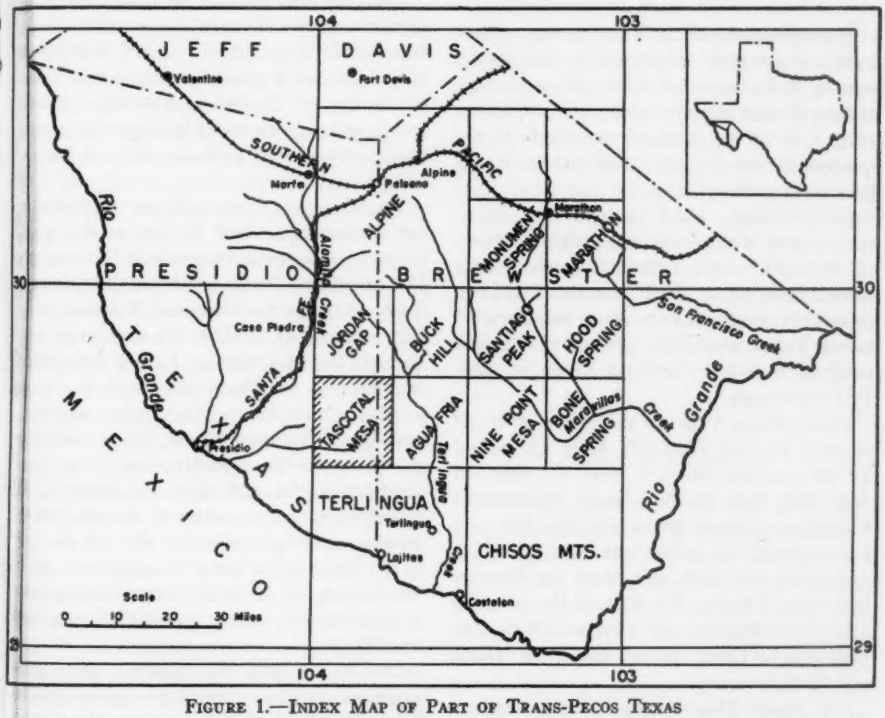

FIGURE 1.—INDEX MAP OF PART OF TRANS-PECOS TEXAS

Showing Tascotal Mesa and adjacent quadrangles mapped as part of the West Texas project of the Bureau of Economic Geology, The University of Texas: Buck Hill, Goldich and Elms (1949); Jordan Gap, Goldich and Seward (1948); Agua Fria, Moon (1953).

guilla. Sagebrush and creosote bush are found on the valley flats, and catclaw grows near the waterways. Bunch grass is the principal natural forage of the livestock and is abundant on mesa tops if there is enough rain.

Topographic Development

The topography in the Tascotal Mesa quadrangle was largely developed by differential erosion. Rock types and structure are the controlling factors in the development of mesas (Pls. 4, 5) in the northern two-thirds of the quadrangle and of rugged hills and steep valleys in the southern third.

Green Valley, which occupies the northeastern part of the quadrangle, has an altitude of 3600–3700 feet. Igneous intrusives form Needle Peak (Pl. 4, fig. 2) and The Dike, two prominent landmarks on this flat lowland. Green Valley is drained by creeks that flow eastward and join Terlingua Creek in Agua Fria quadrangle.

Facing Green Valley is the 700- to 800-foot scarp of Bandera Mesa (Pl. 4, fig. 1), capped by the resistant Mitchell Mesa rhyolitic tuff flow that dips 2° SW. Small, intermittent consequent streams follow the dip slope and are captured by subsequent streams which flow north and south and divert the drainage into South Canyon. The scarp of the mesa has also been breached by streams which flow eastward to Green Valley and form Middle and North canyons.

San Jacinto Mountain in the northwest part of the quadrangle is a basaltic intrusive that rises 700 feet above the level of Bandera Mesa. La Viuda, 2¼ miles southwest of San Jacinto, is a smaller intrusive.

The west-central part of the quadrangle is occupied by Tascotal Mesa which rises approximately 800 feet above Bandera Mesa to form the third major erosional level in the quadrangle. The mesa is capped by a thick series of basalt flows which are more resistant than the underlying Tascotal tuff but which weather more readily than the silicic tuff flow capping Bandera Mesa. The Rawls flows on Tascotal Mesa dip southwest, and the drainage is westward to Alamito Creek. A dendritic drainage pattern is developed on the Rawls basalt in contrast with the more linear drainage pattern on the rhyolitic tuff flow of Bandera Mesa, reflecting the different weathering qualities of the two caprocks. The highest point on the quadrangle, 5184 feet above sea level, is on the scarp of Tascotal Mesa south of the center of the quadrangle.

The porphyritic Rawls flows weather to irregular scarps and steep slopes, whereas the fine-grained nonporphyritic flows weather to thin slabs which generally form gentle slopes (Pl. 5, fig. 2). The alternation of porphyritic and nonporphyritic flows produces a rugged topography marked by many canyons, buttes, and peaks.

There is a great topographic contrast between the southern third and the rest of the quadrangle because the surface rocks in the southern part are chiefly Rawls basalt which have been displaced along the east-west Tascotal Mesa fault. Numerous small faults associated with igneous intrusive masses further complicate the structure and have influenced the topographic development. The major westward drainage is Torneros Creek, whose course is guided by the Tascotal Mesa fault. The eastward drainage through Alamo de Cesario Creek is guided by a secondary fault zone which trends roughly east-west and which is thought to be related to the larger Tascotal Mesa fault. The drainage divide between these two streams is approximately along the 103°50′ longitude line (Pl. 1).

The Alazan Hills are dissected, plateaulike remnants of flows capped by trachyandesite porphyry. Steep-walled canyons characterize the upper reaches of the creeks. La Mota Mountain near the western boundary of the quadrangle is a smaller plateaulike remnant with very steep slopes. On the west side of La Mota Mountain a large toreva block has been displaced vertically about 200 feet. Northwest of La Mota Mountain is a symmetrical domical uplift, the La Mota dome, which has been breached and eroded to a basin. Resistant plugs of microsyenite and gabbro form small spires in the basin.

The southeastern corner is the most rugged and inaccessible part of the quadrangle. The dip slope of Cretaceous rocks off the Solitario uplift (Pl. 2, fig. 1) has been complicated by

rhyolitic intrusives and by intricate faulting. Steep hills formed by the intrusives rise to altitudes approaching 4900 feet.

Pediments

Pediments slope gently to the east away from the receding scarps of Bandera and Tascotal mesas. The largest "rock cut" surface beveled the Duff and Pruett tuff in Green Valley and marks a former base level of erosion in the development of Green Valley. The pediment is now being dissected by renewed active downcutting in the area. The pediment remnants form prominent gravel-capped ridges in the northeastern part of the quadrangle which extend across Green Valley parallel to the present drainage system. These ridges are 30 to 40 feet high and are capped with 3 to 5 feet of unconsolidated gravels. Southward along the eastern border of the quadrangle, the pediment is being dissected by Point Draw and its tributaries. To the south, the rim of Alamo de Cesario canyon is capped with 15 feet of pediment gravels, but all traces of the pediment south of the canyon have been removed except for an isolated, narrow, three-pronged, gravel-capped ridge of tuff on the north side of Tascotal Mesa fault (Pl. 1). This ridge is level with the rim of Alamo de Cesario canyon.

Smaller isolated pediments are forming on Bandera Mesa south and northwest of Wire Gap by the recession of the scarp of Tascotal Mesa. The soft sand and tuff units below the caprock weather easily and promote sapping of the caprock so that large blocks give way and tumble to the bottom of the slope where they disintegrate to a gruss. The writer believes these pediments are the result primarily of weathering and retreat of the mesa scarp by marginal fragmentation, sapping, sheet wash, and rill wash. Lateral planation by streams probably has been a minor process.

Cretaceous System

General Statement

A thick section of Cretaceous rocks, principally limestone, is exposed in the southeast corner of the quadrangle for approximately 8 square miles. Along the south boundary of the quadrangle the Cretaceous strata form the northeastern flank of the Solitario uplift; dips are high (20°–30°), and hogbacks are developed in the thick-bedded limestones of the Comanche series (Pl. 2, fig. 1). North of the Solitario the regional dip is 10° or less, and cuestas result from the erosion of the Boquillas formation of the Gulf Series. (Pl. 2, fig. 2).

The pattern of the Cretaceous strata is complicated by faults and by numerous rhyolitic intrusives. The structural complications together with the rugged topography and general inaccessibility of this part of the area have limited the field studies of the Cretaceous formations, and few reliable observations of thicknesses could be made. It is estimated that the Cretaceous rocks exposed in the quadrangle exceed 2500 feet in thickness (Table 1). The formations, from youngest to oldest, differentiated on the geologic map (Pl. 1) are: Boquillas limestone, Buda limestone, Grayson clay, Devils River limestone, Glen Rose limestone.

Glen Rose Limestone

The single exposure of the Glen Rose limestone in the quadrangle, on the southern boundary, is best seen along the road that leads into the Solitario. In the inner rim of the Solitario basin the lowermost Cretaceous strata were measured by Scott (1939, p. 985) who found nearly 3000 feet for the Trinity section at Fresno Peak on the southwest side of the Solitario, approximately 5 miles south of the quadrangle boundary.

Only the upper part of the Glen Rose occurs in the Tascotal Mesa quadrangle. A 4-foot thickness of hard, reddish-pink, siliceous limestone, in beds averaging 8 inches thick, marks the top of the formation (Robert Haynie, personal communication, 1949). Hard, dark-gray, fine-grained limestone alternates with softer beds of marl and marly limestone. Some beds contain numerous *Orbitolina texana*; the uppermost of these is 30 feet below the ledge-forming, hard, siliceous limestone.

Weathering of the Glen Rose limestone is influenced by widespaced joints. Exposures are etched and corroded to rough irregular surfaces, and where the beds dip steeply a typical

TABLE 1.—GEOLOGIC FORMATIONS IN THE TASCOTAL MESA QUADRANGLE

Age	Group and formation	Thickness in feet (exposed)	Correlation	Lithology and remarks
Quaternary	Alluvium	10±		Valley fill and recent stream alluvium
	Gravel	15±		Pediment and high-level gravels
	Angular unconformity			
(Miocene?)	Buck Hill volcanic series: Rawls basalt	50–937	Probably equivalent to Chisos beds, Vieja series, Square Peak volcanic series, McCutcheon volcanic series	Interfingering flows and volcanic breccia ranging from basalt to trachybasalt and trachyandesite porphyry with intercalated tuff, sandstone, and conglomerate
Tertiary (Oligocene)	Tascotal tuff	797		Sandstone and conglomerate member in upper part; grades to massive conglomerate and fresh-water limestone facies laterally. Light-colored rhyolitic tuff in lower part
	Mitchell Mesa tuff-flow	0–70		Pink to gray rhyolitic tuff flow
(Eocene?)	Duff tuff / Pruett tuff	2000±		Duff; light-colored rhyolitic tuff with minor conglomerate and fresh-water limestone; intercalated basalt flows in upper part. Pruett; dull-colored rhyolitic tuff with minor sandstone and conglomerate. Contact uncertain.
	Angular unconformity			
Gulf	Boquillas	600±	Eagle Ford	Alternating flaggy limestone and shale; calcareous shale predominant in upper part
Cretaceous Comanche	Buda	61	Buda	Massive nodular limestone
	Grayson	65	Grayson	Clay-shale with thin sandy limestone layers
	Devils River	500–600	Georgetown Kiamichi Edwards Walnut-Comanche Peak	Massive limestone with abundant chert nodules
	Glen Rose	1500±	Maxon Glen Rose	Massive, dark-gray limestone

development of solution furrows forms lapies (Smith and Albritton, 1941, p. 73).

Devils River Limestone

Udden (1907a) gave the name Devils River limestone to thick-bedded, fine- to coarse-grained limestone exposed along the Devils River in Val Verde County. These beds are equivalent to the Edwards and Georgetown formations of central Texas. In the Shafter district Ross and Cartwright (1934, p. 596) included beds in the Devils River limestone that originally were referred by Udden (1904) to the Edwards and that were described by him to include the Comanche Peak, Edwards, and Georgetown formations. Eifler (1943, p. 1626) included the beds above the Maxon sandstone and below the Del Rio (Grayson) formation in the Santiago Peak quadrangle in the Devils River limestone.

The writer has mapped as Devils River limestone all the beds above the Glen Rose and below the Grayson. The sequence of alternating hard, thick-bedded limestone, soft nodular limestone, and marl is so similar in over-all appearance that subdivision in the badly faulted exposures seemed impractical. There are two areas of outcrop; the smaller and more accessible one can be reached by the road to the Solitario. At this locality about 135 feet of marly limestone grading upward to limestone is included in the lower part of the Devils River. The marly beds, which probably are equivalent to the Walnut and Comanche Peak formations, contain numerous *Exogyra texana*. They are succeeded by 400–500 feet of thick-bedded, fine-grained, gray to buff limestone that locally contains abundant chert nodules. The beds dip about 20° NW, and their truncated surface is overlain by gently dipping flows of the Tertiary Rawls basalt.

The second and larger area of Devils River limestone is in the southeastern corner of the quadrangle and is not readily accessible. The outcrops here are largely the dip slope off the Solitario uplift and represent the upper part of the Devils River. Along the east boundary remnants of the Grayson formation are capped by Buda limestone, but the Devils River-Grayson contact generally is covered by slumped material.

The thickness of the beds mapped as Devils River limestone is not known. Adkins (1932, p. 346) gives 800 feet for the thickness of the Edwards formation in the inner rim of the Solitario. Robert Haynie (personal communication, 1950) states that the measured thickness of the Georgetown limestone in Santa Elena Canyon of the Rio Grande is 950 feet. It is unlikely that these thicknesses are exceeded in the Tascotal Mesa area. The Kiamichi formation, between the Edwards and the Georgetown in other areas, was not recognized in the quadrangle.

Grayson Clay

The Grayson (Del Rio) is composed of light greenish-yellow to yellow-brown calcareous clay-shale with thin layers of hard clayey and calcareous sandstone. The latter commonly contain abundant *Haplostiche texana* (Conrad). In the southeastern part of the quadrangle the Grayson is repeatedly exposed by small normal faults. Except where protected by the overlying thick-bedded, resistant Buda limestone, the Grayson is easily eroded, and exposures are typically gentle slopes of hills and ridges (Pl. 2, fig. 2).

South of elevation 4038 the Grayson crops out in gentle slopes beneath the Buda. Here the formation is about 65 feet thick; colluvium covers much of the slope and obscures the lower contact. On the east boundary, about three quarters of a mile north of the southeast corner, the Grayson and Buda are exposed in a 30-foot section of which the lower 10–12 feet is Grayson. The base of the Buda is an oyster shell bed, 4 inches thick, and the uppermost bed of the Grayson is a laminated, light-yellow clay, 3 inches thick. The fine-grained claystone is jointed and slickensided; the fractures are marked by thin seams of dark reddish-brown to purplish clay similar to that of the main body except for color.

Buda Limestone

The thick-bedded, fine-grained Buda is more resistant and more persistent cuesta- and ridge-forming unit than either the underlying Grayson clay or the overlying flaggy limestone of the Boquillas. The lower limestone beds, 6 or more

feet thick, form steep to vertical walls and overhanging ledges (Pl. 2, fig. 2) where the underlying Grayson clay has been eroded. Fresh, massive-appearing Buda is white to gray, but it weathers to dark-gray nodular forms. In many places the limestone is shattered and weathered exposures have a rubble of sharp angular pieces. The lighter color and weathering characteristic generally distinguish it from the thick-bedded limestone of the Devils River, but, where the two formations are brought together along faults, the distinction is not always easily made. South of elevation 4038 the Buda is 61 feet thick, and this thickness appears to be rather uniform in all exposures.

The contact of the Buda limestone and Grayson clay is well exposed at the locality on the east border of the quadrangle, three quarters of a mile north of the southeast corner where a 4-inch bed of oyster-shell coquina marks the base of the Buda. The shells are fragmentary and broken, and the coquina probably is a basal conglomerate. Locally small pieces of the Grayson containing *Haplostiche texana* were found in the lowermost beds of the Buda. Although the Grayson and the Buda appear to be concordant, their relations probably are disconformable (Goldich and Elms, 1949, p. 1140). The upper contact of the Buda generally is covered with float derived from the weathering of the overlying Boquillas. It is well exposed, however, in a canyon cut through these formations in the vicinity of BM 4088. The undulating contact (Pl. 3, fig. 1) is marked by a change from the thick-bedded, fine-grained, cream-colored Buda to the thin-bedded, sandy limestone of the Boquillas.

The Buda is fossiliferous and contains nautiloids, ammonites, gastropods, and pelecypods. Fossils in the thick-bedded lower and upper units are difficult to remove, and the middle marly unit yielded little identifiable material.

Boquillas Formation

The Boquillas is the youngest Cretaceous formation exposed in the quadrangle. The largest outcrop, arcuate in shape, is part of the Cretaceous dip slope and is 3 miles long and about 1¼ miles wide. A small erosional remnant of the Boquillas on the eastern boundary extends a short distance into the Agua Fria quadrangle and measures less than half a mile across. Two small outcrops are related to domical structures. An arcuate-shaped outcrop of Boquillas limestone that almost surrounds a small intrusive of riebeckite soda rhyolite is believed to have been pushed up by the intrusive action. This outcrop is in a small upthrown block approximately 1 mile south of the Holland-Meriwether ranch house (near BM 4224). A symmetrical dome of the Boquillas surrounded by Tertiary tuff beds occurs three quarters of a mile north of the Tascotal Mesa fault near the eastern border of the quadrangle.

A maximum thickness of 600 feet is estimated for the Boquillas formation in Tascotal Mesa quadrangle. The lower beds of the Boquillas are well exposed in the creek near BM 4088 (Pl. 3, fig. 1). Thin-bedded, fine-grained limestone persists up from the base for about 65 feet with a relatively minor amount of interbedded calcareous shale. Higher in the section, thicker beds of limestone become numerous, and the amount of calcareous shale gradually increases.

PLATE 2.—CRETACEOUS FORMATIONS

FIGURE 1. SOLITARIO UPLIFT

Steeply dipping Lower Cretaceous limestones on the northeast flank of the Solitario.

FIGURE 2. GRAYSON-BUDA CONTACT

Clay slope of the Grayson formation capped by ledge of thick-bedded Buda limestone.

PLATE 3.—BOQUILLAS FORMATION

FIGURE 1. BUDA-BOQUILLAS CONTACT

Thick-bedded nodular Buda limestone overlain by flaggy Boquillas limestone. In canyon at BM 4088.

FIGURE 2. BASAL PRUETT CONGLOMERATE

Close-up of basal Pruett conglomerate resting on the dissected surface of the Boquillas dome.

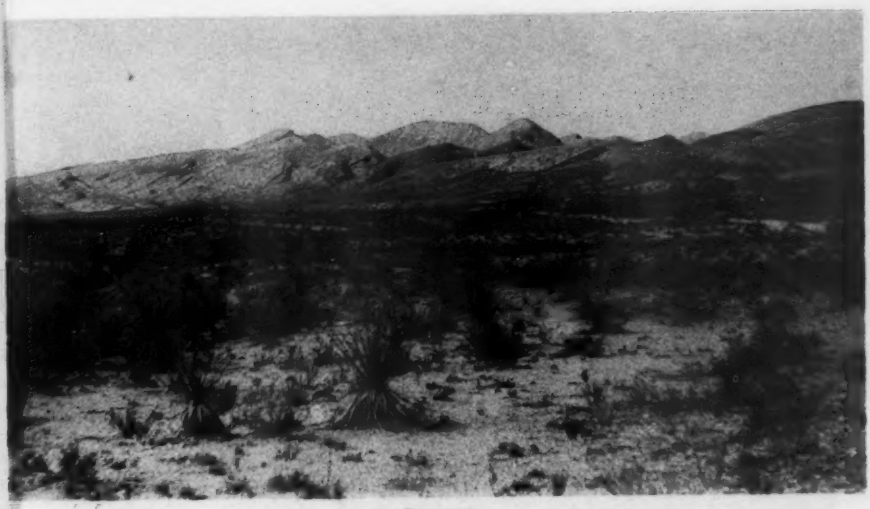

FIGURE 1

FIGURE 2

CRETACEOUS FORMATIONS

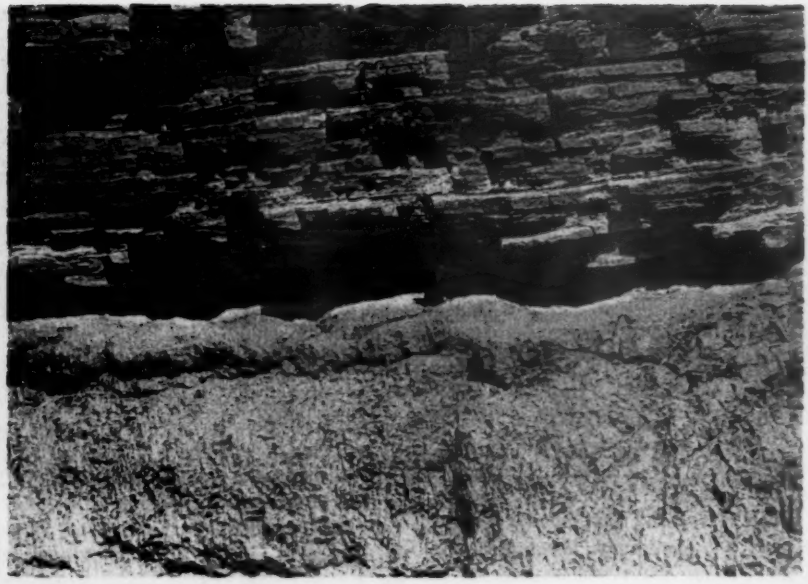

FIGURE 1

FIGURE 2

BOQUILLAS FORMATION

FIGURE 1

FIGURE 2

DUFF FORMATION

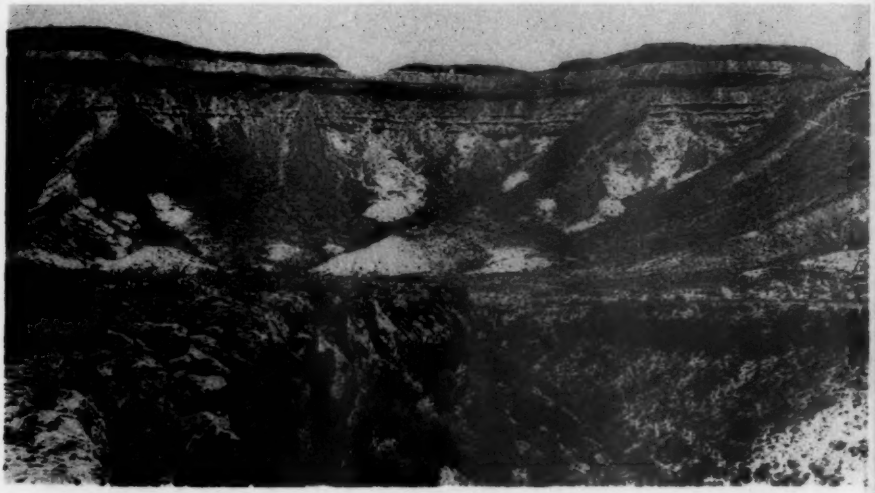

FIGURE 1

FIGURE 2

TASCOTAL FORMATION AND RAWLS BASALT

The Boquillas is well exposed in the canyon east of Hill 4220 and south of the Solitario fault. In the lower part of this section the beds dip 11° N., but to the north, in the vicinity of the fault, the dip increases to 34°. Imprints of *Inoceramus* are numerous in the Boquillas limestone exposed in the canyon south of the Solitario fault. Fragments of a fish with well-preserved teeth and jaw were collected from the outcrop around the small rhyolite intrusive south of the Holland-Meriwether ranch house.

The upper contact of the Boquillas is an erosion surface overlain by different rocks of the Buck Hill volcanic series. At Hill 3837, north of the Tascotal Mesa fault, limestone-pebble conglomerate of the Pruett rests on the Boquillas. In the area of the largest Boquillas outcrop, the formation is overlain by relatively thin beds of the upper Tascotal conglomerate capped by flows of the Rawls basalt. On the east slope of Hill 4850 the Boquillas is overlain by the upper conglomerate member of the Tascotal formation.

Tertiary System

Buck Hill Volcanic Series

The Buck Hill volcanic series was named by Goldich and Elms (1949, p. 1133) for outcrops in the Buck Hill quadrangle (Fig. 1). The succession of tuff, sandstone and conglomerate, breccia, fresh-water limestone, and intercalated lava flows was divided into a lower tuff formation, the Pruett, 900–1000 feet thick; and an upper tuff, the Duff, 1000–1400 feet thick. Separating the Pruett and the Duff are the Cottonwood Spring basalt flows, 50–325 feet thick.

Capping the Duff tuff on Mitchell Mesa in the northwestern corner of the Buck Hill quadrangle is a silicic rock that Goldich and Elms named the Mitchell Mesa rhyolite. This rock is genetically related to the welded tuffs or ignimbrites and is here referred to as Mitchell Mesa tuff flow.

The younger tuff beds that rest on the Mitchell Mesa tuff flow and the flows that cap these rocks west and southwest of the Buck Hill quadrangle were included by Goldich and Seward (1948) in the Buck Hill volcanic series. The tuff beds are well exposed in the scarp of Tascotal Mesa and so were named the Tascotal formation. The flows were named the Rawls basalt for the Rawls ranch on the mesa.

The Pruett formation crops out in Green Valley (Pl. 1). The Duff formation, with unnamed intercalated basalt flows in the upper part, is exposed in the scarp of Bandera Mesa and trends northwest across the northern two-thirds of the area. In the present mapping, however, it was not practicable to map the contact between the two formations in Green Valley because of the lack of differentiating criteria and because so much of Green Valley is covered with gravel and alluvium.

The Mitchell Mesa tuff flow caps Bandera Mesa and is overlain in the central and western parts of the quadrangle by the Tascotal formation. At the type locality, Wire Gap (Pl. 5,

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Plate 4.—DUFF FORMATION

Figure 1. Duff Tuff in Scarp of Bandera Mesa

Duff formation capped with Mitchell Mesa tuff flow below elevation 4475 in Green Valley. Dark layer near top of section consists of three basalt flows, 72 feet thick.

Figure 2. South Canyon, Bandera Mesa

Upper part of the Duff formation capped by Mitchell Mesa tuff flow. Microsyenite dike forming Needle Peak in Green Valley in background.

Plate 5.—TASCOTAL FORMATION AND RAWLS BASALT

Figure 1. Tascotal Formation at Wire Gap

Type section of the Tascotal formation, 800 feet thick, capped by Rawls basalt porphyry. Mitchell Mesa tuff flow in foreground.

Figure 2. Tascotal Formation and Rawls Basalt

Upper sandstone-conglomerate member of the Tascotal formation overlain by 338 feet of Rawls basalt. View from highway, looking northwest at southern end of Tascotal Mesa.

fig. 1), the Tascotal formation is divided into a lower sandy tuff member and an upper tuffaceous sandstone and conglomerate member, but these are not shown separately on the map. In the southern part of the quadrangle where the volcanic series thins and wedges against the Solitario uplift, the upper member grades to thick, coarse conglomerate and fresh-water limestone. This facies is differentiated on the map (Pl. 1).

The writer divides the Rawls basalt flows into four types; trachybasalt porphyry, basalt, trachyandesite porphyry, and volcanic breccia (Pl. 1). The various units of the Buck Hill volcanic series are summarized in Table 1. The aggregate thickness of approximately 3800 feet of the Tertiary volcanic succession is progressively exposed from northeast to southwest in the Tascotal Mesa quadrangle.

Pruett Formation

The gray to reddish-brown tuff, tuffaceous sandstone, and conglomerate of the Pruett formation exposed in the beds of Crystal Creek, Dogie Creek, Point Draw, and unnamed intermittent streams can be traced eastward into the Agua Fria quadrangle where Moon (1953) mapped the basal conglomerate. The regional dip is 1°–3° SW., and, although the alluvial cover in Green Valley obscures the structural relationships, a minimum thickness of the order of 2000 feet is indicated for the tuff beds between the basal conglomerate, 5–6 miles to the east in the Agua Fria quadrangle, and the Mitchell Mesa tuff flow on Bandera Mesa. This thickness corresponds to the combined thickness of the Pruett and Duff formations in the type area to the northeast.

Gray to brown and reddish-brown tuff with some beds of calcareous, medium-grained to conglomeratic sandstone are exposed in Crystal Creek. The tuff is well stratified in beds up to 1 foot thick and has a well-developed joint system. The more prominent set of joints trends N.30°–35°W. Weathering results in nodular forms that are characteristic of the Pruett.

Two fossil localities which yield large low-spired, fresh-water snails are indicated on Pl. 1. The first is an exposure of tuff in a small hill just north of the old Cotter ranch house north of Needle Creek; the second is in an old stone corral about 1½ miles west, on the south side of the creek. At both localities the poorly preserved snails appear to be similar. Unidentifiable bone fragments were found with the snails in the sandy tuff in the old corral. Above the tuff is cross-bedded, crudely ripple-marked sandstone and conglomeratic sandstone in which white tuff fragments contrast sharply with the dark reddish-brown matrix. These beds are mapped as undifferentiated Pruett-Duff (Pl. 1). The snail-bearing beds at the Cotter ranch are mapped as Pruett, but positive identification is not possible, and they may be equivalent of either the Pruett or the Duff formations to the north.

Duff Formation

The Duff formation in the scarp of Bandera Mesa in the northeastern part of the quadrangle is dominantly thick-bedded, fine-grained, variegrated tuff. Colors range from light gray to buff, brown, pink, and red. Locally the tuff is sandy, grading to tuffaceous sandstone, conglomeratic sandstone, and boulder conglomerate. The most persistent conglomerate beds are near the top of the formation. The tuff is chiefly rhyolitic glass in various stages of alteration and is similar to the beds in the northern parts of the Buck Hill and Jordan Gap quadrangles (Goldich and Elms, 1949, p. 1610), but in several respects the Duff in the Tascotal Mesa quadrangle differs from the formation farther north. The beds commonly are calcareous, and there are layers of fresh-water limestone as well as intercalated basalt flows in the upper part which have not been found in either the Jordan Gap or Buck Hill quadrangles.

Three sections of the Duff beds were measured in the scarp of Bandera Mesa, and these give many of the lithologic details. A section, 764 feet thick, was measured with the plane table below elevation 4475 (Pl. 4, fig. 1) west of Needle Peak.

	Thickness (feet)
Mitchell Mesa tuff flow	
(19) Rhyolitic tuff flow with iridescent feldspar and quartz crystals in fine-grained groundmass	11
Duff formation	
(18) Covered interval, probably tuff	53
(17) Tuff, chalky white, fine-grained, speckled, sandy, massive; pitted and weathered to roughly rounded nodular forms	15

		Thickness (feet)
(16)	Tuff, sandy and conglomeratic with large calcareous tuff concretions; upper part fine- to medium-grained tuff in successive receding benches 4–6 feet thick. Tops of benches are hard calcareous tuff layers about 2 feet thick; weathers to earthy mud-flow slopes. Lower part sandy and conglomeratic with local lenses of limestone, and cherty limestone cobbles, and felsitic igneous pebbles. Lenses about 4 inches thick	68
(15)	Basalt intercalations	
	Basalt flow No. 3: black, fine-grained, amygdaloidal, green-stained; calcite fillings; weathers spheroidally	30
	Basalt flow No. 2: black, fine-grained, locally stained green; well-developed flow breccia at top; weathers spheroidally	11
	Basalt flow No. 1: dark-green, fine-grained, vesicular; thick flow breccia at top with numerous quartz fillings	31
(14)	Tuff, white to buff, conglomeratic to fine-grained; upper part massive, thick-bedded, fine-grained; baked hard, red at contact with overlying flow; lower part well stratified, chalky white, black-speckled, hard, locally conglomeratic	11
(13)	Conglomerate, conglomeratic sandstone, and sandstone, reddish-brown, poorly stratified, poorly sorted; base is conglomeratic with pebbles of tuff, porphyritic felsites, fossiliferous limestone, black chert, red vesicular basalt fragments; grades to thin, cross-bedded lenses of medium-grained, buff, calcareous sandstone; upper 10 feet hard, massive conglomerate with boulders up to 15 inches in diameter; cliff former	14
(12)	Tuff, variegated, light-gray, buff and pink, fine-grained, numerous tuffaceous limestone concretions up to 1 inch in diameter; massive beds, 2–10 feet thick, separated by buff, earthy, soft tuff. Forms massive, sheer cliff	86
(11)	Tuff, light-gray, fine-grained, containing numerous gray limestone concretions up to 6 inches in diameter; mottled tuff breccia near top with light-gray calcareous matrix containing angular pink tuff fragments up to 1 inch in length	35
(10)	Tuff, salmon-red, fine-grained, three 6-inch conglomeratic layers near top with pieces of tuff and felsites, ⅛–¼ inch long; thin-bedded, weathers to irregular slope with many ledges	20
(9)	Tuff, calcareous, massive, buff to light-gray, fine-grained, forms steep cliff with pitted surface	106
(8)	Tuff, in part calcareous, variegated pink and light gray; base marked by hard 4-inch bed of fine-grained white, black-speckled tuff, weathers gray; upper part sandy, weathers to irregular slopes of large nodular forms	29
(7)	Tuff, sandy, buff, fine-grained, black-speckled, massive, weathers with steep faces; two pink, hard, calcareous tuff bands in the upper part	52
(6)	Tuff, calcareous, alternating light pink and light gray with occasional purple bands, thin- to thick-bedded; purple bands finely fractured with yellow-green alteration along fractures; weathers to irregular nodular pieces; thicker calcareous beds weather spheroidally	60
(5)	Tuff, variegated pink and light gray, massive, cut by small clastic dikes; pitted surface; weathers to small irregular pieces	21
(4)	Tuff, in part calcareous, predominantly pink with few gradational light-gray bands; calcareous beds hard and concretionary	7
(3)	Covered interval, probably tuff	42
(2)	Tuff, calcareous, variegated pink to light gray, fine-grained; more calcareous strata stand out prominently in thick massive beds, less calcareous tuffs occupy slopes between	38
(1)	Covered interval, probably tuff, to floor of Green Valley	24
	Total thickness measured	764

The upper Duff beds were measured in the first canyon north of Middle Canyon, on the spur that forms the west wall of the creek just north of the Seminole Trail. A basalt flow caps the spur, and the main bed of conglomerate, here 15 feet thick, is 146 feet below the base of the flow. Tuff and conglomerate beds aggregate 254 feet in this section.

In the northwest wall of South Canyon at a point opposite the debouchment of the northwestward-flowing tributary, 22 feet of conglomerate is exposed at the base of the section in the stream bed. Ten feet above the top of the conglomerate is a basalt flow, 22 feet thick. About half way up the slope 4 feet of limestone, in beds about 4 inches thick, forms a resistant ledge (Pl. 4, fig. 2).

The conglomerate beds in the upper part of the Duff are lenticular; the bed which occurs 88 feet below the caprock in South Canyon is not found to the north below elevation 4475 where the first prominent conglomerate is 219 feet below the tuff flow. Coarse red conglomerate, approximately 50 feet thick, is the caprock of the small butte east of Smugglers Gap about 300 feet below the level of Bandera Mesa. The cobbles and boulders in this conglomerate include limestone, cherty limestone, marble, quartzite, black chert, epidote rock, riebeckite felsite, trachyte, scoria, vesicular and amygdaloidal andesite or basalt, and tuff pieces. The conglomerate is underlain by a basalt flow and tuff beds in which, near the

base of the hill, are beds of hard, fine-grained, white, tuffaceous limestone.

In the southeastern part of Bandera Mesa and in the north walls of Alamo de Cesario canyon a red conglomerate marks the top of the Duff formation. The conglomerate, up to 50 feet thick, is poorly sorted with a range from small pebbles to boulders 2 feet in diameter. The base of the conglomerate commonly exhibits a well-developed scour-and-fill structure. Channels scoured in the tuff beds are filled with gravel showing cross-lamination, with a concentration of larger cobbles in the troughs.

An unusual conglomerate developed on the northeast flank of the Solitario uplift was described by Moon (1953, p. 182) in the Agua Fria quadrangle. The poorly sorted conglomerate has a yellow, calcareous, sandy cement, and "yellow conglomerate" used by Moon is a convenient name for reference. This conglomerate was traced from the Agua Fria quadrangle along the Tascotal Mesa fault to South Fork in the Tascotal Mesa quadrangle. A maximum thickness of about 50 feet is developed on the eastern boundary. Moon described one locality in the Agua Fria area where a "welded tuff" of rhyolitic composition is included in the conglomerate. Similar relations exist in the Tascotal Mesa quadrangle, half a mile east of Hill 4202, where the writer mapped the "welded tuff" as the Mitchell Mesa rhyolite tuff flow. The yellow conglomerate is a local lentil in part older and in part younger than the tuff flow.

Basalt flows were mapped at two horizons in the Duff formation (Pl. 1). One lower flow, 200–300 feet below the rim of Bandera Mesa, east of Smugglers Gap, is a dark-gray, fine-grained basalt with a well-developed friction breccia at the base. This flow has a maximum thickness of about 50 feet, and its outcrop is about 2 miles in length. The upper basalt intercalations are much more extensive and can be followed in the scarp from a point 2½ miles southeast of Smugglers Gap northwestward to a point south of North Canyon near the north boundary.

The flows at the upper level are variable in number. In the measured section at elevation 4475 (Pl. 4, fig. 1) three flows total 72 feet in thickness. Vesicular and amygdaloidal zones at the tops and friction breccias at the bottoms are characteristic. Only one flow, 20–25 feet thick, is present in Middle Canyon and South Canyon.

In thin section the flows are fine-grained, diabasic olivine basalt and trachybasalt. The rock consists of small slender laths of labradorite, 60–70 per cent, with intersertal olivine, augite, and magnetite-ilmenite. Hydrothermal alteration formed much serpentine, hematite, secondary magnetite, and calcite.

Pruett-Duff Beds

The outcrops between the Tascotal Mesa fault and the north rim of Alamo de Cesario canyon are designated Pruett-Duff. This area is a westward extension of the Devil's Graveyard of the Agua Fria quadrangle and is a desolate and barren badlands. The scarp of Alamo de Cesario canyon is composed of variegated, light-pink to light-gray, nodular, calcareous tuff with minor coarse, light-gray, cross-bedded sandstone. At Hill 3837 near the eastern boundary, a conglomerate similar to the typical basal Pruett conglomerate laps unconformably on the dissected surface of a small structural dome in the Boquillas limestone. The conglomerate (Pl. 3, fig. 2) is made up of well-rounded pebbles and cobbles of limestone with a few of chert, but none of igneous rocks. It is poorly cemented and pinches out up dip against the dome.

	Thickness (feet)
Pruett-Duff	
(7) Tuff, calcareous, brown, soft, bentonitic; weathers to gentle slopes	12
(6) Limestone, tuffaceous, light gray, fine-grained, well-bedded, brown on weathered surface	3
(5) Tuff, sandy, light gray, flaky; weathers to mud-cracked, sandy, clayey slopes	36
(4) Limestone, brown, fine-grained	3
(3) Sandstone, light gray, medium-grained, conglomeratic	1
(2) Conglomerate, well-rounded, dark gray and gray limestone pebbles and cobbles most abundant; black chert pebbles few; igneous pebbles wanting	9
Boquillas limestone	
(1) Limestone, yellowish-gray, thin-bedded, silty. To base of section in creek bed	13
Total thickness measured	77

Mitchell Mesa Tuff-flow

The Mitchell Mesa tuff flow covers about 35 square miles of Bandera Mesa. Small patches

of the tuff flow crop out south of the rim of Bandera Mesa as remnants on small hills. There are two other minor areas of outcrop; the larger of these is the thin ribbon of "rhyolite" which parallels Tascotal Mesa fault on the downthrown side near the eastern border of the quadrangle. To the south, in the creek bed on the northwest side of Hill 4850, a rhyolitic rock very similar to typical Mitchell Mesa tuff flow forms a small fault block which has been dropped down against Boquillas limestone.

The "rhyolite" is resistant to erosion and exhibits well-developed columnar jointing. It has a pinkish to bluish-gray and white groundmass with numerous pyramidal quartz and opalescent, tabular feldspar crystals. The fresh rock is fine-grained and breaks with an even fracture. The weathered rock is greasy black to reddish brown and commonly is pitted or cavernous. The weathered surface usually is rough due to the protuberance of quartz and feldspar crystals which are more resistant than the matrix. Locally the matrix is vesiculated and in a few localities exhibits flow structure around inclusions. Both the inclusions and vesiculated patches tend to be elongated.

The upper and lower contacts of the tuff flow commonly are marked by a soft, soapy, bentonitic clay containing quartz and feldspar crystals and retaining the texture of the fresh rock. The clayey material represents weathered zones from a few inches to 18 inches thick, ranging from white to pink and green. The clay is not an ancient soil but resulted from chemical alteration of the glassy groundmass following deposition of the overlying Tascotal formation. The Tascotal beds were deposited on a hummocky erosion surface of the Mitchell Mesa tuff flow, and it is unlikely that conditions favored preservation of the soft bentonitic clay on the surface. The development of the clay at the base of the formation likewise precludes surface weathering.

Along the Tascotal Mesa fault in the southeastern part of the quadrangle, the tuff flow strikes west and dips 70° S. At the contact with the underlying yellow conglomerate is an 18-inch layer of decomposed rhyolite. The fresh rock differs from the typical tuff flow in that it is softer and feels distinctly ashy or gritty.

The maximum thickness of tuff flow in Tascotal Mesa quadrangle, 60–70 feet, is in the rim of North Canyon at the northern border of the quadrangle. The sheet thins to the south and is only 24 feet thick in the southeast rim of Bandera Mesa.

In thin section, the Mitchell Mesa rhyolitic tuff flow consists of a fine-grained matrix of glass shards and their devitrification products, and crystals of anorthoclase (2V = 40°) and quartz. Magnetite and apatite are accessory minerals. Alteration and secondary products include hematite, leucoxene, calcite, and chalcedonic quartz. The anorthoclase crystals are embayed and rounded; faint gridiron structure can be detected.

Tascotal Formation

Description.—At the type section at Wire Gap (Pl. 5, fig. 1) the Tascotal formation is 797 feet thick and is divided into two members, a lower member of tuff and sandy tuff beds and an upper member of sandstone, tuffaceous sandstone, and conglomerate. A section was measured at Wire Gap.

		Thickness (feet)
	Rawls basalt	
(26)	Trachybasalt porphyry (Trbp), dark brownish gray, porphyritic with occasional stubby plagioclase phenocrysts; lower 2 feet vesicular and amygdaloidal with fillings of chalcedony and calcite; base is reddish brown and ropy. To top of mesa.	60
(25)	Tuff, sandy, pumiceous, some 1- to 2-inch beds almost entirely light-green pumice; color changes from grayish brown through yellow brown to baked red at the contact with overlying flow; weathers irregularly to alternating small ledges and slopes. The ledges have a greater abundance of pumice	49
(24)	Conglomerate and coarse sandstone, alternating, well bedded ranging from 6-inch layer of sandstone to 2-foot layers of conglomerate; middle conglomerate is dark brown containing many vesicular flow fragments; forms ledge	8
(23)	Tuff, sandy, fine-grained, brown, with scattered light-green pumice fragments up to 3 inches long; weathers to thinly laminated shaly appearance	2
(22)	Sandstone, soft, buff, conglomeratic with scattered igneous pebbles; weathers to soft, irregular slope making bedding	12
(21)	Trachybasalt porphyry, dark gray, porphyritic, with numerous plagioclase laths; weathers to brown resinous appearance in which light plagioclase phenocrysts are conspicuous; surface disintegrates irregularly to small angular fragments ap-	

	Thickness (feet)
proximately 1 inch in diameter. Forms massive, dark-brown, sheer cliff	65
(Thickness of Rawls basalt 196 feet)	
Tascotal formation	
Upper sandstone and conglomerate member	
(20) Covered interval; probably sandy tuff	30
(19) Tuff breccia, soft, crumbly, light gray, contains tuff fragments, weathered pumice, feldspar crystals	5
(18) Conglomerate and coarse sandstone, alternating; contains well-rounded pebbles	28
(17) Tuff, sandy, pumiceous, light gray	2
(16) Conglomerate and coarse sandstone, alternating, light gray to buff; conglomerate beds usually not over 2 feet thick, with some beds of coarse sand 4–6 feet thick; pebbles and cobbles similar to unit No. 13	20
(15) Conglomerate, predominantly cobbles, roughly bedded, cemented with coarse sand, forms prominent ledge; cobbles roughly concentrated in 2-inch to 1-foot parallel bands; many flat cobbles oriented parallel to the bedding plane; igneous cobbles predominate, chiefly trachyte, andesite, vesicular basalt; phanerites scarce. Sedimentary cobbles chiefly light-gray chert and well-rounded, flattened crystalline limestone	5
(14) Sandstone, tuffaceous, soft, buff, contains few thin conglomeratic lenses 2–3 inches thick. Upper 6 feet hard and fritted on surface; weathers to soft slope covered with talus	25
(13) Conglomerate, light gray to buff; considerable range in size, well-rounded pebbles, cobbles, boulders of igneous felsites, scoria, chert, hard tuff fragments; cemented with coarse tuffaceous sand; many flat pieces roughly oriented in parallel alignment; moderately stratified with interbedded and lensing coarse sand layers; faintly cross-bedded; variable thickness laterally due to channeling. One scoria boulder 15 inches in greatest diameter	10
(Note: Line of section for remainder of Tascotal tuff is offset 200 yards north)	
(12) Sandstone, soft, poorly cemented, fine-grained, buff; weathers to soft, treacherous slope in upper 20 feet; lower part more tuffaceous and forms vertical ledge with pitted surface; beds thick, massive, but bedding planes masked by disintegration on surface	36
(11) Sandstone, tuffaceous, soft, buff, becoming light gray near top; disintegrates to fine sand on surface; massive, predominantly thick-bedded. Interbedded conglomeratic sands 1 foot thick occur at 25- to 30-foot intervals; weathers to steep, smooth slopes	194
(10) Tuff breccia-conglomerate, distinctive pink and white weathered pumice fragments, few scattered hard tuff pieces; forms steplike benches about 3 feet thick	10
(9) Sandstone, tuffaceous, soft, light gray, fine-grained; weathers to smooth massive gentle slope; bedding obliterated	24
(8) Sandstone, tuffaceous, buff to sandy tuff; weathers to large roughly rounded nodular forms; forms massive steep-faced ledges about 25 feet high in sharp contrast to soft, gentle-sloped units above and below	46
(7) Sandstone, tuffaceous, soft, poorly cemented, brownish gray, fine-grained to locally coarse-grained; weathers to soft sandy, gentle slopes; middle 25 feet well indurated	71
Lower tuff member	
(6) Tuff, sandy, light gray, forms gentle slopes with some irregularly spaced ledges 3–4 feet thick; weathers to small roughly rounded, scaly, nodular pieces; more resistant ledges form boulder nodules; bedding fairly well developed with right-angle jointing system striking N.27°W. and N.70°E.	113
(5) Tuff, sandy, light gray, fine-grained, thick-bedded, forms ledges 5–6 feet thick in steplike fashion; weathers to large, roughly rounded pieces; jointed in same manner as unit No. 6	31
(4) Tuff, sandy, poorly cemented, light gray; forms uniform gentle slope; weathers to flaky, spalled surface	37
(3) Tuff, sandy, variegated light gray, and red, well stratified; becomes increasingly more red toward top	60
(2) Tuff, light gray, thin-bedded with local massive beds, fine- to medium-grained; thin beds weather to typical tabular flags	37
(1) Covered interval, tuff beds away from line of section to top of Mitchell Mesa rhyolite tuff flow	13
(Thickness of Tascotal formation 797 feet)	
Total thickness measured	993

Lower tuff member.—The lower tuff member, 291 feet thick at Wire Gap, consists of light-gray to pink, sandy tuff with some small discontinuous lenses of conglomerate at the base. Locally the tuff is coarse-grained and speckled with biotite flakes. The beds are predominantly thin and weather to tabular blocky pieces. At Wire Gap local thick beds are channel fillings; the thick beds cut abruptly across the thin strata giving the impression of faulting, but the beds above are undisturbed.

The contact with the underlying Mitchell Mesa tuff flow is poorly exposed in the type section but is clearly exposed northwest of Wire Gap along a small normal fault southeast of BM 4075. The top of the rhyolitic tuff flow is a soft, bentonitic clay with numerous quartz and feldspar crystals preserving the original texture of the rock. The base of the Tascotal is a soft, crumbly conglomeratic sand containing fragments derived from the underlying tuff flow. A section was measured.

	Thickness (feet)
Tascotal formation	
(6) Tuff, light gray, medium-grained, sandy; weathers to 2- to 4-inch slabs	2.5
(5) Tuff, soft, cream-colored, bentonitic, crumbles easily	5.0
(4) Tuff, light gray, sandy, hard; contains white tuff pieces; locally stained green	5.0
(3) Tuff, bentonitic, chocolate brown near base to light gray near top; contains soft soapy green bentonite pieces	6.5
(2) Tuff, conglomeratic, red, contains white tuff pieces	0.3
Mitchell Mesa tuff-flow	
(1) Clay, bentonitic, soft, soapy, brown, with quartz and glassy feldspar crystals	1.5
Total thickness measured	20.8

The lower part of the Tascotal formation is fairly uniform throughout the quadrangle, but there is considerable variation in the thickness and coarseness of the conglomerate near the base. One thousand feet south of elevation 3869 in the small creek at the eastern edge of the northwest rectangle a thick basal conglomerate contains boulders of syenite, vesicular basalt, and riebeckite rhyolite, up to 3 feet in diameter. Approximately 0.4 mile west across a wide stream bed and on the north side of the road, the conglomerate contains abundant riebeckite rhyolite cobbles in a sandy red matrix.

Upper sandstone and conglomerate member.—At Wire Gap, the upper sandstone and conglomerate member of the Tascotal formation, 506 feet thick, consists of soft sandstone, tuffaceous sandstone, and conglomerate. There is considerable channeling, lensing, and cross-bedding. The conglomerates consist of well-rounded pebbles, cobbles and boulders of felsites, scoria, chert, hard tuff fragments, and limestone. At the southern end of Tascotal Mesa west of the Marfa-Lajitas road, a poorly sorted, massive, and well-indurated conglomerate contains black ribbon chert and white novaculite derived from the Maravillas chert and Caballos novaculite formations of Ordovician and Devonian age. These rock types disappear to the north and were not found in the upper conglomerate at Wire Gap. One boulder of novaculite measured 1 foot in diameter. Gray to greenish-blue riebeckite rhyolite, red and yellow jasper, limestone pebbles and cobbles, and hard, white marble pieces are present. Silicic felsites, up to 1 foot in diameter, are abundant. On the average, the pieces are subrounded to subangular; however, limestone pebbles and cobbles are well rounded. A few basaltic flow pieces were noted. The cementing material is calcium carbonate.

The massive, thick conglomerate is cut by the major fault which strikes northwest across the face of the southern end of the mesa. Because this unit is a local development adjacent to the Solitario, it must have been derived from the uplift, which indicates that this great dome was a structural high being eroded during the deposition of the upper Tascotal. Associated with the conglomerate beds at this locality is fresh-water limestone, marking the first appearance of limestone in the Tascotal formation. Silicified plant stems found in tuffaceous limestone above the conglomerate were examined by Mr. Roland Brown of the U. S. Geological Survey who made this memorandum (January 25, 1950):

> "Fine striations and fluting on the stemlike specimens in this sample indicate that the specimens represent remains of plants, but whether grasses, sedges, or other kinds, is not determinable. Little or no cellular structure can be seen in cross-sections, the replacement by silica being practically complete."

East of the Marfa-Lajitas road, the Tascotal thins appreciably, and limestone becomes relatively more abundant. In the northwest corner of the southeast rectangle, a section measured below Hill 4681 included 77 feet of fresh-water limestone.

	Thickness (feet)
Rawls basalt	
(6) Basalt flows to top of hill	407
Tascotal formation	
(5) Tuff breccia, dark brown, baked hard and brittle, pops apart when struck with hammer	11
(4) Limestone, light yellow, medium-grained, sugary-textured, flaggy; beds average 1 to 4 inches thick; weathers gray	72
(3) Limestone, light yellow, medium-grained, lower part bedded grading into soft, nodular, massive limestone in upper part; weathers gray	5
(2) Conglomerate, yellow, poorly sorted, poorly indurated, massive with calcareous cement; contains chiefly black chert and novaculite pieces up to 8 inches in diameter; limestone cobbles up to 4 inches; soda rhyolite boulders up to 1 foot; and pieces of tuff	3
(1) Tuff, sandy, medium-grained; to creek bottom	2
Thickness of Tascotal beds	93

Between the Tascotal Mesa fault and the Agua Fria Trail, the upper member consists of fresh-water limestone and conglomerate. In all exposures examined the conglomerate contains abundant black chert, novaculite, limestone, and silicic felsites. The conglomerates are interbedded with yellow, thin-bedded (1–2 inch) clayey limestone which resembles the upper part of the Boquillas.

Fresh-water limestone is less abundant to the south and is not present in the upper member south of the Augua Fria trail; massive conglomerate is the chief rock type and is well exposed south of Hill 4850 where boulder conglomerate rests on a Boquillas erosion surface. Huge blocks of Glen Rose (?) limestone and rhyolite up to 8 feet in diameter as well as 3- to 4-foot Boquillas flags are abundant. The large rhyolite blocks were derived from the intrusive of Hill 4850. This fact coupled with the absence of any basaltic flow pieces in the conglomerate offers convincing evidence that the rhyolite intrusives antedate the upper Tascotal beds and the Rawls basalt flows.

A similar relationship exists around the small intrusive hill 1 mile south of the Holland-Meriwether ranch house (west of BM 4224) where the Boquillas is domed by an intrusion of rhyolite. In the creek bed on the west side of the hill, the Boquillas is overlain concordantly by a hard, fine-grained, thick-bedded, fresh-water limestone. Both the Boquillas and the fresh-water limestone dip 12° off the hill. A single specimen of a fossil snail resembling *Helix hesperarche* was found in the fresh-water limestone. Below the exposure of the fresh-water limestone, a 50-foot thickness of coarse conglomerate laps on the domed Boquillas beds and encircles the hill. Locally derived pieces of the Boquillas limestone are abundant at the base of the conglomerate. Large cobbles of Caballos novaculite and of black chert are numerous, but particularly instructive are the abundant large pieces of rhyolite which were derived from the intrusive. The conspicuous absence of basaltic pieces in the conglomerate leaves little doubt that the conglomerate is older than the Rawls basalt with which it is faulted into juxtaposition.

The beds of fresh-water limestone at this locality are a remnant of the Tertiary beds that at one time rested on the Boquillas and that formed part of the succession into which the rhyolitic magma was intruded. Uplift accompanying the igneous activity accelerated erosion, and the Tertiary beds were largely eroded. The exposed intrusive and Boquillas beds supplied float that was incorporated in the younger conglomerate of the upper Tascotal which on the south side of the hill is succeeded by beds of tuff and fresh-water limestone and finally by flows of the Rawls basalt.

Basalt intercalation.—West of Wire Gap, a black, fine-grained basalt flow is intercalated in the upper part of the Tascotal about 50 feet below the top of the formation. The basalt has a limited lateral extent of 3–4 miles and does not occur at Wire Gap nor at the western border of the quadrangle. The thickness ranges from a maximum of 17 feet down to 1 foot. The lower 3–4 inches is vesicular, and the top is amygdaloidal with fillings chiefly of calcite. The broken amygdaloidal top contains fills of sand with angular pieces of basalt. The flow is overlain by conglomerate containing amygdaloidal fragments up to 5 inches in diameter.

Stratigraphic relations.—The Tascotal formation in the northern three-fourths of the quadrangle rests on the Mitchell Mesa tuff flow, but in the southeast rectangle, south of the Tascotal Mesa fault, it lies unconformably on Boquillas limestone and on older Cretaceous formations. The Tascotal thins to the southeast against the flank of the Solitario uplift, and only the upper conglomerates and limestone were deposited in this area (Fig. 2). Evidence suggests that the lower units of the Buck Hill volcanic series may have once been present on the flank of the uplift but were eroded before deposition of the Tascotal.

Rawls Basalt

Description.—The Rawls basalt flows cover approximately 110 square miles of the quadrangle. Four rock types were recognized in the field: (1) trachybasalt porphyry or "birds-eye" porphyry which usually contains abundant plagioclase phenocrysts up to 2 inches long and weathers to rough, dark-brown surfaces; (2) a fine-grained, dark-gray basalt which

weathers to thin slabs; in the outcrop, it characteristically forms gentle-sloped, round-topped hills covered with platy talus pieces; (3) dark, reddish-brown, hard, dense, volcanic breccia particularly well developed in the northern part of the southwest rectangle; and (4) a dark-gray to greenish-gray trachyandesite porphyry in which the plagioclase phenocrysts are much smaller and considerably less abundant than in the "birds-eye" porphyry. In the trachyandesite small phenocrysts of pyroxene are common.

Although the rock types interfinger, the trachybasalt porphyry is usually basal, the basalt in the middle, and the trachyandesite porphyry uppermost and nowhere covered by younger flows. The volcanic breccia is restricted to the southwestern part of the quadrangle and interfingers with flows of basalt. The section at La Mota Mountain in the southwestern part of the quadrangle was measured.

	Thickness (feet)
Rawls basalt	
(5) Trachyandesite, thick, massive, fine- to medium-grained; numerous small phenocrysts of pyroxene and plagioclase; weathers brown. To top of La Mota Mountain	356
(5) Basalt, dark gray; weathers to thin slabby pieces; slopes covered with talus	40
(4) Trachybasalt porphyry, abundant plagioclase phenocrysts up to 1 inch long; weathers to irregular angular pieces	81
(3) Volcanic breccia, massive, hard, dark brown, containing twisted and contorted basalt pieces	30
(2) Trachybasalt porphyry, massive; numerous light to dark feldspar phenocrysts up to ¼ inch long; forms first massive outcrop in La Mota Mountain	129
(1) Trachybasalt porphyry, consists of several flows with abundant plagioclase phenocrysts up to 1 inch in length. To base of exposure	301
Total thickness measured	937

Trachybasalt porphyry. — Trachybasalt porphyry is the most abundant of the lavas. The flows range from 48 to 300 feet in thickness on the rim of Tascotal mesa, increase to an average of 350 feet to the southwest in the central part of the mesa, and attain their greatest thickness, 511 feet, in La Mota Mountain. The rock forms massive, sheer cliffs in contrast to the gentle-sloped hills of fine-grained basalt. The texture is diabasic, and glassy plagioclase phenocrysts, ½–2 inches in diameter, are abundant. Some of the rock contains small pyroxene phenocrysts. The groundmass weathers to a dark-brown, resinous color in which the light-colored plagioclase phenocrysts are conspicuous. The surface disintegrates irregularly to small angular fragments. Well-developed amygdaloidal tops and bottoms have calcite and chalcedony fillings.

The rock at Wire Gap is olivine-augite trachybasalt porphyry. The plagioclase phenocrysts, 30–40 per cent, are labradorite. Some phenocrysts exhibit pronounced zoning in which the zoning bands are contorted, fractured, and displaced; these range from andesine to labradorite. Other phenocrysts (An_{55}) are fresh and unzoned although fractured and corroded. The augite, 15 per cent, is pale purple and slightly pleochroic. Olivine is largely altered to iddingsite or bowlingite. Magnetite-ilmenite is abundant, 10–15 per cent of the rock. The groundmass contains orthoclase, 15 per cent, and a plagioclase, oligoclase-andesine, 15 per cent. Apatite is an accessory mineral, and hematite and calcite are alteration products. A pale-brown interstitial material is probably devitrified glass. Thin sections of the "birds-eye" porphyry from other localities show variations from olivine trachybasalt to olivine trachyandesite.

The trachybasalt flows moved into the Tascotal Mesa quadrangle from the southwest, and just west of the quadrangle boundary in the dome at La Mota dikes of the trachybasalt porphyry ("birds-eye" porphyry) cut the Tascotal tuffs. These dikes were perhaps the feeders of the flows.

Basalt.—Basalt flows are extensive in the southern third of the quadrangle. The rock is uniformly fine-grained, dark-gray basalt that weathers to thin slabs and commonly forms talus slopes where it underlies porphyritic rocks of the other units. In the northwest corner of the southeast rectangle, the Rawls flows consist entirely of basalt, 320 feet thick. This is the greatest development of this unit in the quadrangle.

The succession at Hill 4633 about 1¾ miles south of the Alazan ranch house includes 155 feet of basalt. The flows thin westward and are

missing on the west side of the Alazan Hills although 40 feet is recorded in the 937-foot section at La Mota Mountain.

A thin section of the analyzed specimen (Table 3, col. 1) collected just east of elevation 4307 about three quarters of a mile west of the Holland-Meriwether ranch house contains 60–70 per cent labradorite (An_{62}). The rock has a diabasic texture, and the plagioclase laths are mantled with orthoclase. Augite, 15 per cent, is slightly pleochroic; olivine crystals have been completely altered to bowlingite or iddingsite. Small grains of a dark red-brown mineral may be lamprobolite. Magnetite-ilmenite is abundant, and patches of secondary calcite are common.

Volcanic breccia.—This unit is the least abundant of the four types mapped and is restricted to the southwestern part of the quadrangle. The best exposure is on the north side of Torneros Creek opposite elevation 4003 where the breccia forms the rimrock and is 60–70 feet thick. The rock is hard, dense, reddish brown, and contains basalt fragments up to 4 inches long which locally are in parallel alignment. The pieces commonly are curved and contorted. In thin section, broken feldspar crystals and rock fragments are common in a matrix of glass fragments which appear fused. The feldspar crystals are rimmed with orthoclase, and basic rock fragments are oxidized. This rock is classified as a welded breccia.

Seventy-four feet of volcanic breccia is exposed on the north side of Torneros Creek; 30 feet, at La Mota Mountain; 21 feet, in the Alazan Hills; and 27 feet, at Hill 4633. The unit is conspicuous in the field and is a useful marker bed. It is restricted to the upper part of the Rawls and usually underlies trachyandesite porphyry.

Trachyandesite porphyry.—A dark-gray, fine-grained rock with small phenocrysts of plagioclase and pyroxene is well developed in the southwestern part of the quadrangle and attains a thickness of 356 feet in La Mota Mountain. A thickness of 91 feet caps the Alazan Hills, and the flows extend northeastward to Hill 5184 on the rim of Tascotal Mesa where a thickness of 125 feet was measured. There is one other small outcrop, 27 feet thick, on the rim of the mesa at VABM 4125 (stamped 4132). The flows weather light brown and develop blocky talus slopes. Near the top of La Mota Mountain huge blocks, 50 by 25 feet, contain angular pieces up to 6 feet across. There is no vesiculation, and the breccia is restricted to the east side of the mountain. This locality may represent a conduit from which the trachyandesite lavas were extruded. The trachyandesite flows are restricted to the upper part of the Rawls formation and nowhere are overlain by younger volcanic rocks.

The rock from Hill 5184, on the rim of Tascotal Mesa, consists of fine-grained orthoclase and oligoclase, 80 per cent, with well-defined flow structure. There are a few corroded phenocrysts of oligoclase (An_{27}). Olivine has been altered to iddingsite or bowlingite. An unusual yellow-green amphibole, 5 per cent, with low birefringence and extinction of about 28° has not been identified. Small grains of augite are contained in the groundmass. Magnetite-ilmenite and apatite are accessory. This rock is assigned Johannsen number 2211 E, olivine trachyandesite porphyry.

At La Mota Mountain the plagioclase is slightly more silicic, and the rock is coarser-grained. Thin sections from other localities show variations in the amount of augite, but the plagioclase remains in the medium range. Two chemical analyses are given in Table 3.

Tuff and breccia beds.—The succession of Rawls flow rocks is interrupted by thin beds of tuff, volcanic breccia, sandstone, and conglomerate in addition to the mapped volcanic breccia. At Wire Gap, two porphyritic basalt flows, totaling 125 feet in thickness, are separated by a unit, 72 feet thick, which consists of tuff, pumiceous tuff, sandy tuff, and conglomerate. The tuff beds are commonly baked red at the contact with overlying flows. They thin to the southwest and are rare in the southwest rectangle.

At Hill 4633, 1¾ miles south of the Alazan ranch, there are a number of thin conglomerate, breccia, and hard, fine-grained tuff beds between the flows, including two 1-foot beds of hard, brittle, grayish-green and red rock containing a few scattered, reddish-brown volcanic pieces averaging a quarter of an inch in diameter.

Half a mile southwest of BM 4224 near the

Holland-Meriwether ranch house in the southeast rectangle, a hard, compact tuff breccia, 3 feet thick, lies between flows of basalt. The rock grades from a tuff breccia at the base to a banded, baked, dense, highly oxidized rock at the contact with the overlying flow. In thin section the lower rock is a mixed tuff containing anorthoclase crystals, quartz, silicic plagioclase laths, lamprobolite, pyroxene and apatite grains, and rock fragments in a groundmass of glass shards which appear partly fused. The fragments and crystals are rounded and corroded.

The upper part of the bed is banded, brownish-red and black. Anorthoclase, quartz, silicic plagioclase, and rock fragments are imbedded in a groundmass of brownish-red to black glass which has flowed and molded around the crystals and fragments. The thin sections reveal a gradation from an indurated and baked tuff-breccia to a rock partly fused by the heat of the succeeding lava flow as it moved across the tuff bed. Selective fusion of the more silicic pieces produced a soft glass which responded to the movement and pressure of the overlying lava and developed a striking flow texture. Chemical analyses of these rocks are given in Table 5.

Stratigraphic relations.—The Rawls basalt flows are the youngest member of the Buck Hill volcanic series in the Tascotal Mesa quadrangle, and their upper erosion surface is locally overlain by Quaternary gravel deposits. The flows rest on the Tascotal formation and in places interfinger with beds of tuffaceous sandstone, breccia, and conglomerate. In the southeastern part of the quadrangle, overlap on the flanks of the Solitario uplift brings the flows on the Devils River limestone.

Age and Correlation

The age and correlation of the Buck Hill volcanic series has been discussed by Goldich and Elms (1949, p. 1143–1145) and by Goldich, Elms, and Seward (1949, p. 67). They assigned the Pruett to the Eocene and the Duff to the Oligocene. The Tascotal formation, younger than the Duff, may also be of Oligocene age, but the probability that these beds and the overlying Rawls flows are Miocene cannot be dismissed. Fresh-water snails, bone fragments, and plant remains collected on the Tascotal Mesa quadrangle are of no correlative value.

The Buck Hill volcanic series is equivalent in part to the Chisos beds (Udden, 1907b) in the Big Bend National Park area, the Square Peak volcanic series (Huffington, 1943, p. 1027) in the Quitman Mountains, the McCutcheon series in the Barilla Mountains (Eifler, 1951, p. 342), and the Vieja series (Vaughan, 1900, p. 77) in the Tierra Vieja Mountains.

Quaternary System

The Quaternary deposits are divided into gravel and alluvium. The gravel deposits are thin veneers on pediments and channel and basin fills at higher levels above the present base level of erosion. The alluvium is valley fill and recent deposits along stream courses.

Gravel is most widespread in Green Valley where it forms thin protective sheets on a pediment which was formed as the scarp of Bandera Mesa retreated. Renewed downcutting has dissected this surface leaving gravel-capped ridges that parallel the present stream courses. These deposits are seldom more than 3–4 feet thick, and all are mapped as gravels, although there is much finer material. Similar pediment gravels are found on Bandera Mesa extending away from the scarp of Tascotal Mesa.

High-level gravels are present on Tascotal Mesa and are conspicuously exposed on the west side of the Marfa-Lajitas road where it ascends the basalt hills. At this locality the gravel clearly represents an old narrow channel deposit and consists chiefly of dark-gray basalt boulders up to 3 feet in diameter. The boulders are cemented with secondary calcium carbonate, caliche, so that the well-indurated rock might easily be mistaken for an older Tertiary conglomerate.

The largest gravel-covered area on the mesa is in the south-central rectangle. These gravels probably were deposited in a shallow structural basin as a result of the erosion of surrounding upthrown fault blocks. The deposit of hard caliche-cemented silt and gravel is being dis-

FIGURE 2.—DIAGRAMMATIC CROSS SECTION

Showing stratigraphic relations of Buck Hill volcanic series to Cretaceous rocks on the northeast flank of the Solitario uplift: (Pal) Paleozoic, undifferentiated; (Klr) Trinity conglomerate and coarse sandstone; (Kgr) Glen Rose limestone; (Kdv) Devils River Limestone; (Kgs) Grayson clay; (Kbu) Buda limestone; (Kbo) Boquillas limestone and calcareous shale; (Tpt) Pruett tuff; (Tdt) Duff tuff; (Tmmr) Mitchell Mesa rhyolite tuff flow; (Ttt) Tascotal tuff; (Trb) Rawls basalt flows.

sected by numerous, small, intermittent tributaries of Torneros Creek.

Alluvial deposits are mapped in Green Valley and in the northwestern part of the quadrangle on Bandera Mesa. The deposits are chiefly fine-grained silty material, and in many places in Green Valley the creeks have well-developed meanders where they flow on this material. Steep-walled banks expose a thickness of as much as 10 feet of alluvium.

The writer often observed the rapid deposition of stream alluvium in the vicinity of the old San Jacinto ranch on Bandera Mesa. During heavy thundershowers torrential streams, carrying a tremendous load of silt and sand, would overflow their banks, spread out in braided pattern, and deposit 2–3 feet of sediment in a few hours. Much of this material was then removed by wind erosion during protracted dry spells.

Intrusive Igneous Rocks

Rhyolitic Intrusives

The soda rhyolite forming Hill 4778 on the southern border just east of the road leading into the Solitario is the largest silicic intrusive in the quadrangle; it covers about 1 square mile. The body is concordant with Glen Rose limestone on the south, but elsewhere it cuts the limestone, and small apophyses of rhyolite have nearly vertical contacts. The fresh rock is creamy white, fine-grained rhyolite porphyry with glassy feldspar phenocrysts as much as a quarter of an inch in length. The outcrop weathers brown.

In thin section, the analyzed specimen (Table 2, col. 2) is porphyritic with a fine-grained groundmass of feldspar and quartz. The feldspar in the groundmass is orthoclase and silicic plagioclase. The phenocrysts are chiefly anorthoclase. Optical data for the anorthoclase are $\gamma = 1.530 \pm .002$, $(-)$ $2V$ small to moderate, $X\Lambda a = 10°$. Quartz phenocrysts are less numerous and usually occur in anhedral aggregates. Mafic minerals are restricted to fine shreds largely altered to iron oxides. Kaolinite is a weathering product.

Rhyolite forming Hill 4850, 1½ miles north of the quadrangle border, and the hill just to the northeast, has a dark speckled appearance caused by aggregates of small riebeckite grains. Hill 4850 is about 1 mile in length and rises approximately 600 feet above the surrounding Cretaceous and Tertiary rocks. Upper Tascotal conglomerate and Rawls flows lap against the intrusive mass on the eastern and southern edges. At the north end of the northernmost hill, the intrusive has baked the Boquillas limestone to a hard marble. Rhyolite vitrophyre, exposed on the northwest flank, is probably related to a former vent which served as a zone of weakness for the later emplacement of riebeckite soda rhyolite.

Tascotal Mesa fault cuts through the middle of a riebeckite soda rhyolite mass just west of the Presidio-Brewster county line. A zone of brecciated rhyolite, 20 feet wide, marks the fault. The fine-grained, gray to pink rhyolite at the border of the intrusive grades to coarser-grained, typical riebeckite rhyolite near the top of the hill. The upper Tascotal conglomerate that surrounds the hill laps up on the rhyolite slopes and is younger than the intrusive.

Flows of Rawls basalt surround the riebeckite rhyolite intrusive in the southeast corner of the south-central rectangle and are clearly younger. The rhyolite is variable in color and patchy in appearance. Light-purplish patches contain shreds of a mafic mineral, probably originally riebeckite, that have been oxidized to a reddish brown. Deeper blue areas contain fresh riebeckite. This relation suggests bleaching of the rock as a result of alteration.

On the south edge of the intrusive, rhyolite vitrophyre is closely related to the riebeckite rock, but the precise relations could not be determined. The brown perlitic glass contains euhedral phenocrysts of feldspar and quartz, which constitute about 20 per cent of the rock. Optical data for the anorthoclase follows: $\alpha = 1.524$; $\gamma = 1.530 \pm .002$; $(-)$; $X\Lambda a = 10°$. Spherulites of silicic feldspar are abundant, and there are a few euhedral crystals of aegirin-augite and magnetite. The index of the glass, $1.505 \pm .002$, is similar to that of the glass at Hill 4850 and in La Mota dome.

Thin sections of the riebeckite soda rhyolite from the several intrusives show little variation. The riebeckite is strongly pleochroic

from deep lavender blue to dark green to yellow green. The mineral occurs in spongelike dendritic masses and poikilitically includes quartz and feldspar grains. Phenocrysts of anorthoclase range from a maximum of 2 mm. down to sizes only slightly larger than the feldspar in the groundmass. Quartz is restricted to the groundmass in which it is abundant.

Basaltic Intrusives

San Jacinto Mountain, with a relief of approximately 800 feet, is the most imposing intrusive structure in the area; it rises to an altitude of 4750 feet. Most of the mountain including the tall spire is in Jordan Gap quadrangle. It was formed by the intrusion of a fine-grained analcime-olivine trachybasalt that punched up a large block of the Buck Hill volcanics approximately 400 feet above the level of Bandera Mesa. The flanks are Tascotal tuff through which the magma rose, pushing ahead of it a segment of the Duff tuff, Mitchell Mesa tuff flow, and Tascotal tuff.

La Viuda is a small, roughly circular hill, 2 miles southwest of San Jacinto, composed chiefly of basaltic vent agglomerate that cuts the Tascotal tuff beds. The hill is cut by two vertical, highly fractured and weathered dikes at right angles to each other striking N. 60° W. and N. 30° E. The top of La Viuda is composed of agglomerate including large pieces of a dark-gray basalt similar to the dike rock. The vent material is amygdaloidal; fillings are primarily calcite. The rock is an olivine basalt composed of slender labradorite needles with intersertal augite and olivine. Much of the olivine is altered to green serpentine. Apatite and magnetite are accessory, and carbonate is the chief alteration product.

The Dike in Green Valley, just north of Needle Peak, is a fine-grained, black basalt with chilled borders. It trends northeasterly and extends into the Jordan Gap quadrangle making a prominent ridge over a mile long which at some points rises 200–300 feet above the valley floor. It ranges in thickness from a few feet to 20 feet and commonly shows highly polished slickensides. The tuff is baked and indurated to a hard, red rock at the contact.

The dike rock is diabasic and consists of labradorite laths mantled with orthoclase. Subhedral olivine crystals are unusually fresh with minor alteration to green serpentine. Augite is purplish and pleochroic. Analcime is intersertal to the plagioclase laths; magnetite is abundant. This rock is analcime olivine trachybasalt, similar in composition to the San Jacinto intrusive.

Near the southeastern end of Bandera Mesa, a small volcanic vent cuts the Duff tuff and is exposed in the scarp of the mesa. The rock is a dark, reddish-brown, vesicular and scoriaceous agglomerate with vertical scarps up to 100 feet in height. On the east side of the vent, and near the base, a huge boulder of black basalt, approximately 30 feet across and 20 feet high, is included in the agglomerate. This rock is olivine basalt with a microporphyritic texture. Labradorite laths (An_{60}) show flow structure. The plagioclase phenocrysts contain inclusions of magnetite, serpentine, and tiny rods of pyroxene. Much of the olivine is altered to a greenish-brown serpentine. Small shreds of brown biotite, associated with magnetite and serpentine, are deuteric.

A smaller basaltic vent area crops out just south of the rhyolite body cut by the Tascotal Mesa fault. The exposure is about 200 feet wide and 300 feet long. The rock is a brecciated mass of vesicular and amygdaloidal material. Some of the blocks are 8 feet long. The vent cuts upper Tascotal thin-bedded, clayey, fresh-water limestone, and a light-green, soapy bentonite is formed along the contact. The basalt dike west of the vent cuts flows of the Rawls basalt.

Olivine basalt forms a small hill just west of Hill 4850, 1½ miles north of the south boundary. This small, circular, pluglike mass with well-developed columnar jointing intrudes Boquillas limestone and is overlain by the upper Tascotal conglomerate. The Boquillas is baked to a hard marble.

Syenitic Intrusives

A syenite dike northeast of the Wilson ranch house in Green Valley forms Needle Peak, a prominent curved ridge extending northwestward for approximately 1 mile. Differential erosion has produced sharp pinnacles, the

highest of which rises 500 feet above the floor of the valley and gives the mass its name. The dike, ranging in thickness from 1 foot at the southern end to 300 feet at the northern end, has baked and hardened the intruded Duff tuff at the contacts. The indurated tuff is resistant to weathering and forms a thin, wall-like sheath around the dike. Slickensides are well developed within the dike rock and at the contact with tuff.

The Needle Peak dike is an alkalic microsyenite. Silicic feldspar makes up 75 to 85 per cent of the rock. The mafic minerals are fine-grained alkalic pyroxene and amphibole that were not specifically identified, and pale biotite.

Southeast of the Cotter ranch, a small dike, forming a vertical wall 1–15 feet high, extends southeast into the Agua Fria quadrangle. It probably extends to the northwest in the subsurface and connects with the syenite dike that intersects The Dike just to the north on Jordan Gap quadrangle. The southeastern tip of this dike is in Tascotal Mesa quadrangle. The rock, altered to a uniform brown, is fine-grained and diabasic with well-developed flow lines. The plagioclase laths (oligoclase near andesine) are mantled with orthoclase. Magnetite and mafic silicates in large part have been oxidized to hematite, but biotite is fresh and unaltered. A deep reddish-brown mineral may be serpentinous alteration after iron-rich olivine. Abundant calcite encloses and partly replaces the feldspar. A fine-grained clay mineral belongs to the montmorillonite group. Magnetite and needlelike crystals of apatite are accessory. This dike is classified as plagioclase microsyenite or latite.

A greenish-gray dike rock with biotite phenocrysts cuts the Duff tuff about half a mile south of the mouth of North Canyon near the base of the scarp of Bandera Mesa. The weathered rock is brown and contains much limonite. The dike, ranging from a few feet to 15 feet thick, makes a vertical east-west wall, 200 yards long. Baked red tuff adheres to the walls and has highly polished slickensides. The rock is very similar to the plagioclase microsyenite described above.

Near the southern end of Bandera Mesa along the Brewster-Presidio county line, fine-grained microsyenite intrudes the Mitchell Mesa tuff flow forming Hill 4718 and the smaller hill to the north. The outcrop shows columnar jointing which has localized weathering. Hill 4718 is capped with a 10-foot thick remnant of Mitchell Mesa tuff flow that was carried upward by the intruding magma to its present position, 200 feet above the level of Bandera Mesa. This structure is comparable to the trapdoor domes described by Moon (1953, p. 185) in Agua Fria quadrangle. The rock is alkalic microsyenite and in thin section consists of about 90 per cent silicic feldspar in small bundlelike aggregates of laths with well-developed flow structure. Mafic minerals are small shreds of brown biotite and minor amphibole. Magnetite and apatite are accessory.

Syenitic intrusives occur in the small basin formed by erosion of the dome west of La Mota Mountain. The main syenite mass at the south and north peaks in the basin is light colored and medium-grained with small hornblende crystals up to an eighth of an inch in length. On the surface the rock is pock-marked due to weathering and removal of hornblende crystals. The effect of contact metamorphism and soaking of the country rock by the syenite magma is well exhibited in the flanks of the south peak. Sandy, calcareous tuff and conglomerate have been altered to hard, dark-green marble and silicate rock which resembles diorite or gabbro in the hand specimen. The highly metamorphosed contact zone grades to bluish-green, light-colored marble and marbleized conglomerate and finally to unaltered sediments and pyroclastics. The conglomerate at the north peak has not been so intensely altered but is baked and hardened.

The two peaks are connected by a microsyenite dike which continues to the southwest into Shafter quadrangle cutting the Rawls basalt flows. The rock is light grayish green with miarolitic cavities in 3- to 4-inch bands parallel to the trend of the dike. The intruded tuffs and conglomerates are baked and adhere to the dike rock.

Numerous other microsyenite dikes occur in the southwestern part of the quadrangle and appear to radiate from a high, rugged region 4–5 miles southwest of the quadrangle.

In thin section, the analyzed specimen (Table 4, col. 2) from the La Mota dome is an alkalic microsyenite with a hypautomorphic-granular texture. The feldspar, 70–80 per cent, is anorthoclase and albite. The most abundant mafic mineral, 10 per cent, is aegirin-augite. Soda-rich amphibole, probably arfvedsonite, is present in minor amounts. Tiny shreds of a purple-brown strongly pleochroic mineral have not been identified. Apatite is accessory.

In some specimens the dark-green aegirin-augite is altering to greenish-brown hornblende. Some of the larger grains of hornblende contain feldspar inclusions. Magnetite crystallized late in the interstices of the feldspar grains, and hematite and carbonate are alteration products.

Gabbro of La Mota Dome

Two small hills of dark-gray, medium-grained gabbro at the north end of La Mota dome are roughly circular and about 100 feet in diameter. Green to black rhyolitic obsidian is associated with the gabbro, but the relations could not be determined.

Thin sections of the analyzed specimen from La Mota dome (Table 4, col. 1) show a medium-grained, hypautomorphic-granular texture. Labradorite (An_{60}), 50–60 per cent, is mantled with orthoclase. Fresh, euhedral olivine with some green serpentinous alteration, probably antigorite, and augite in small subhedral to euhedral crystals each make up about 10 per cent of the rock. Magnetite-ilmenite is abundant. Analcime is intersertal to feldspar in the groundmass and forms euhedral crystals on the borders of zeolite patches. Other secondary minerals are calcite and kaolin. This rock is an analcime-olivine syenogabbro.

Chemistry and Petrology

Extrusive Rhyolitic Rocks

Rhyolitic glass and its alteration products are the major constituents of the tuffaceous sediments that make up the bulk of the Buck Hill volcanic series. The refractive index of the glass is consistently below 1.50, indicating a silica content in excess of 70 per cent. The tuffs, however, have an admixture of other materials and grade to sandstone, conglomerate, and fresh-water limestone. The sand admixture is particularly evident in the Tascotal formation. Variability in composition under these conditions is to be expected, and samples of the tuff beds in the Tascotal Mesa quadrangle were not chemically analyzed.

The original analysis (Goldich and Elms, 1949, p. 1162) of a sample of the Mitchell Mesa tuff flow from Mitchell Mesa is included in Table 2. Two unpublished analyses of samples from the Jordan Gap quadrangle are plotted in the variation diagram (Fig. 4) and illustrate the potassic character of the rhyolitic tuff flow.

A number of features indicate that the Mitchell Mesa rock is not a typical rhyolitic lava. Wherever the top and the base of the rock have been examined there is a marked absence of vesiculation or brecciation. The upper surface is irregular, and undoubtedly some material has been eroded; nevertheless, the apparent uniformity from top to bottom in numerous exposures is striking. Inclusions of foreign rock have been noted in many places, but the pieces are relatively small and rare.

The presence of glass shards and pumiceous pieces suggests a fragmental rock. Rocks of similar composition and structure have been variously described as welded tuffs (Mansfield and Ross, 1935; Gilbert, 1938), ignimbrites (Marshall, 1935), and tuff flows (Fenner, 1923, 1948). Such rocks are thought to be indurated by recrystallization through pneumatolytic action, and the origin of the Mitchell Mesa rhyolitic tuff flow is ascribed to a similar process. The pumiceous inclusions and the columnar structure are characters which the Mitchell Mesa rock has in common with the tuff flows described by Fenner.

Recrystallized tuff flow may grade from a well-indurated rock to types in which the fragments have been little altered, so that they are more tufflike but are still sufficiently coherent to maintain vertical walls. The writer believes that this explains the soft ashy character of the "rhyolite" on the downthrown side of the Tascotal Mesa fault.

Small amounts of vitrophyre are closely associated with what are considered former

TABLE 2.—CHEMICAL ANALYSES OF RHYOLITIC ROCKS

	1	2	3	4	5	6
SiO_2	73.85	73.10	74.72	75.53	76.71	78.83
Al_2O_3	11.43	14.74	14.12	12.26	12.15	9.95
Fe_2O_3	1.42	.49	.38	1.56	.94	1.40
FeO	.86	.10		.73	.60	.10
MgO	.05	.05	.19	.07	.18	.16
CaO	.14	.38	.26	.16	.05	.35
Na_2O	4.22	4.44	3.77	5.24	4.73	1.78
K_2O	4.66	5.65	4.57	4.05	3.88	6.34
H_2O+	2.53	.38	.95	.00	.31	.41
H_2O-	.14	.12	.33	.13	.11	.11
CO_2	.01	.09	n.d.	n.d.	n.d.	.27
TiO_2	.12	.18	.12	.10	.09	.20
P_2O_5	.00	.02	.02	.01	.02	.03
MnO	.03	.00	n.d.	n.d.	n.d.	.08
BaO	n.d.	tr.	n.d.	n.d.	n.d.	tr.
F	.34	n.d.	n.d.	n.d.	n.d.	n.d.
Cl	.20	n.d.	n.d.	n.d.	n.d.	n.d.
	100.00	99.74	99.99*	99.84	99.77	100.01
Less O ≡ F & Cl	.19					
	99.81					

* Includes 0.56 ignition loss (organic matter).

1. Rhyolite vitrophyre from south slope of large riebeckite soda rhyolite intrusive in southeast corner of south-central rectangle of Tascotal Mesa quadrangle, (field No. TM 294). J. J. Engel, analyst.

2. Soda rhyolite from Hill 4778 on southern border of Tascotal Mesa quadrangle (field No. TM 284). J. J. Engel, analyst.

3. Sodipotassic rhyolite, southwest part of Solitario. R. B. Ellestad, analyst (Lonsdale, 1940, Table 17).

4. Paisanitic riebeckite soda rhyolite, Mountain 4500, Terlingua district. R. B. Ellestad, analyst (Lonsdale, 1940, Table 17).

5. Paisanitic riebeckite soda rhyolite, east of Mountain 4500, Terlingua district. R. B. Ellestad, analyst (Lonsdale, 1940, Table 17).

6. Rhyolite tuff-flow capping Mitchell Mesa, Buck Hill quadrangle. S. S. Goldich, analyst (Goldich and Elms, 1949, p. 1162).

pyroclastic vents now occupied by intrusive masses in the southern part of the quadrangle. Pieces of obsidian, limestone, and other rock types are included in tuff and breccia deposits that mark one of these vents well up on the side at the southern end of Hill 4850, a riebeckite soda rhyolite intrusive. Northeast of Hill 4850, on the north side and near the base of a hill of rhyolite, there is a larger outcrop of obsidian. A third exposure of vitrophyre is on the south edge of the riebeckite soda rhyolite intrusive approximately 4 miles to the southwest near the southern boundary, and this rock is represented in Table 2 (col. 1). A small outcrop of rhyolitic glass is in close proximity to the gabbro intrusive in La Mota dome. In each case it appears that the vitrophyre issued from a vent that later was the site of intrusive action.

The chemical analysis of the vitrophyre shows large relative amounts of water, fluorine, and chlorine. It demonstrates that the vents in the southern part of the quadrangle probably are not the source of the Mitchell Mesa tuff-flow. In contrast, the composition of the glass is similar to that of the analyzed specimens of soda rhyolite and riebeckite soda rhyolite (Table 2).

Intrusive Rhyolitic Rocks

Only one specimen of the intrusive rhyolites was analyzed (Table 2, col. 2) and represents the soda rhyolite at the southern border. The rock is similar in composition to a sodipotassic rhyolite (Table 2, col. 3) described by Lonsdale (1940, p. 1566) from the southwestern part of the Solitario.

The riebeckite soda rhyolite intrusives in the quadrangle, although chemical data are not available, can be expected to be somewhat more sodic than the soda rhyolite and probably will fall within or close to the range indicated in the two analyses (Table 2, cols. 4 and 5) of riebeckite soda rhyolite from the Terlingua district (Lonsdale, 1940, table 17).

TABLE 3.—CHEMICAL ANALYSES OF RAWLS FLOWS

	1	2	3	4
SiO_2	45.86	52.06	60.10	60.36
Al_2O_3	16.52	18.67	17.11	17.69
Fe_2O_3	7.93	5.25	3.35	4.71
FeO	5.03	3.56	2.35	1.36
MgO	4.16	1.97	.97	.79
CaO	8.27	7.07	2.49	1.77
Na_2O	3.83	4.37	5.58	6.34
K_2O	1.66	2.65	5.30	4.89
H_2O+	.86	.54	.32	.32
H_2O-	.74	.69	.18	.14
CO_2	.72	.01	.35	.00
TiO_2	3.43	2.17	1.09	.71
P_2O_5	.56	.71	.35	.32
MnO	.17	.16	.17	.19
BaO	.06	.10	.13	.20
S	.00	.01	.01	.02
	99.80	99.99	99.85	99.81
Less O ≡ S				.01
				99.80

1. Basalt (Trb) east of elevation 4307, west-central part of southeast rectangle (field No. 291).

2. Trachybasalt porphyry (Trbp), lower flow at Wire Gap (field No. TM 29).

3. Trachyandesite porphyry (Tra), top of Hill 5184 on rim of Tascotal Mesa (field No. 81).

4. Trachyandesite porphyry, top of La Mota Mountain (field No. 176).

Nos. 1–3, R. L. Erickson, analyst; No. 4, John Thatcher, analyst.

Extrusive Basaltic Rocks

The oldest flows in the Tascotal Mesa quadrangle are basalt intercalations in the upper Duff beds and are exposed in the scarp of Bandera Mesa. A possible feeder is the small pluglike mass of basaltic agglomerate at the southeastern end of the mesa. No chemical analyses of these rocks were made.

The term basalt is used as a field name for the fine-grained, dark Rawls flows which range from basalt to trachyandesite. Chemical analyses of the three types of flows differentiated on the map (Pl. 1) are given in Table 3. In the sequence, basalt-trachybasalt-trachyandesite, there is a progressive decrease in the relative amounts of iron oxides, magnesia, lime, and titania, and a progressive increase in silica, alkalis, and baria.

On casual inspection the analyzed basalt flow (Table 3, col. 1) appears similar to the analyzed analcime syenogabbro (Table 5, col. 1) from La Mota dome, but the norms (Table 6) emphasize the difference. The undersaturated La Mota rock contains analcime that is represented in the norm in 4.8 per cent of normative nepheline. The Rawls basalt is similar to analyzed samples of the Sheep Canyon basalt flows in the Buck Hill area (Goldich and Elms, 1949, Table 5).

The Rawls flows mapped as trachybasalt porphyry are variable in composition as is indicated in the petrographic description. The single analysis (Table 3, col. 2) of the lowermost flow at Wire Gap sets it off from the analyzed samples of the basalt and the trachyandesite flows, but additional analyses of selected samples would probably show compositions approaching that of the trachyandesite.

The two analyzed samples of the trachyandesite porphyry flows (Table 3, cols. 3 and 4) suggest a high degree of uniformity in composition. Sample No. 3 represents the flow capping Hill 5184 on the rim of Tascotal Mesa where a thickness of 125 feet of trachyandesite flows was measured. Sample No. 4 is from the flow capping La Mota Mountain, 9 miles to the southwest, where the trachyandesite flows are 356 feet thick.

The differences in composition of the Rawls flows may be in part a progressive change re-

sulting from some process of magmatic differentiation; however, the field work shows that the basalt and the trachybasalt porphyry flows alternate and were extravasated from different sources.

TABLE 4.—CHEMICAL ANALYSES OF SYENOGABBRO, MICROSYENITE, AND PLAGIOCLASE SYENITE

	1	2	3
SiO_2	45.98	62.35	51.08
Al_2O_3	16.83	17.37	17.61
Fe_2O_3	3.45	3.48	3.62
FeO	8.94	1.62	.89
MgO	5.12	.31	.72
CaO	6.76	1.41	8.79
Na_2O	4.49	6.43	5.30
K_2O	1.79	5.38	3.66
H_2O+	1.90	.31	.65
H_2O-	.28	.32	.34
CO_2	.19	.00	3.67
TiO_2	3.41	.38	1.52
P_2O_5	.57	.13	1.35
MnO	.16	.14	.12
SrO	n.d.	n.d.	.11
BaO	.05	.04	.24
S	.04	.00	.00
SO_3	n.d.	n.d.	.12
	99.96	99.67	99.79
Less O ≡ S	.02		
	99.94		

1. Analcime syenogabbro from La Mota dome (field No. TM 319). J. J. Engel, analyst.

2. Alkalic microsyenite from La Mota dome (field No. TM 317). J. J. Engel, analyst.

3. Plagioclase syenite dike on east border of quadrangle, 1 mile southeast of Cotter ranch. Sample from northeast end of dike. Eileen H. Oslund, analyst.

Intrusive Basaltic Rocks

A chemical analysis of the medium-grained analcime syenogabbro from La Mota dome is given in Table 4. The relative coarse grain of the gabbro in the La Mota dome suggests that the exposure may be part of a large mass. None of the dikes or pluglike masses of basalt have been analyzed.

Intrusive Syenitic Rocks

The chemical analysis of the intrusive microsyenite in La Mota dome (Table 4, col. 2) is similar to analyzed samples of microsyenite from Buck Hill (Goldich and Elms, 1949, p. 1166) and from Santiago Peak (Clarke, 1904, p. 75).

TABLE 5.—CHEMICAL ANALYSES OF INDURATED AND PARTIALLY FUSED TUFF-BRECCIA BED BETWEEN FLOWS OF RAWLS BASALT

	1	2
SiO_2	69.55	64.66
Al_2O_3	12.28	15.80
Fe_2O_3	4.42	4.62
FeO	.08	.48
MgO	.63	.45
CaO	1.79	1.15
Na_2O	3.08	5.30
K_2O	4.09	5.71
H_2O+	1.25	.42
H_2O-	2.04	.37
CO_2	.04	.07
TiO_2	.69	.68
P_2O_5	.18	.13
MnO	.11	.18
	100.23	100.02

1. Indurated tuff breccia near base of bed resting on Rawls basalt (Trb), half a mile southwest of BM 4224, southwest rectangle (field No. TM 292). S. S. Goldich, analyst.

2. Partially fused tuff breccia, 2 feet above sample No. 1 (field No. 290). R. L. Erickson, analyst.

The unusual composition (Table 4, col. 3) of the dike of plagioclase syenite on the eastern border southeast of the Cotter ranch, is not closely matched in any published analyses of rocks from southern Trans-Pecos Texas. Two analyses of somewhat similar composition represent analcime-plagioclase syenite from the Terlingua district and analcimitic microsyenite from the Solitario (Lonsdale, 1940, Table 17). The Tascotal Mesa dike rock contains a large amount of calcite which may have formed in part from original analcime.

The plagioclase syenite differs from the microsyenite of La Mota dome not only in its

TABLE 6.—CHEMICAL ANALYSES OF TASCOTAL MESA ROCKS AND NORMS OF IGNEOUS ROCKS

Analysts: Nos. 1, 4, 5, 11, R. L. Erickson; Nos. 2, 7, 8, 9, J. J. Engel; No. 3, Eileen H. Oslund; No. 6, John Thatcher; No. 10, S. S. Goldich

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	45.86	45.98	51.08	52.06	60.10	60.36	62.35	73.10	73.85	69.55	64.66
Al_2O_3	16.52	16.83	17.61	18.67	17.11	17.69	17.37	14.74	11.43	12.28	15.80
Fe_2O_3	7.93	3.45	3.62	5.25	3.35	4.71	3.48	.49	1.42	4.42	4.62
FeO	5.03	8.94	.89	3.56	2.35	1.36	1.62	.10	.86	.08	.48
MgO	4.16	5.12	.72	1.97	.97	.79	.31	.05	.05	.63	.45
CaO	8.27	6.76	8.79	7.07	2.49	1.77	1.41	.38	.14	1.79	1.15
Na_2O	3.83	4.49	5.30	4.37	5.58	6.34	6.43	4.44	4.22	3.08	5.30
K_2O	1.66	1.79	3.66	2.65	5.30	4.89	5.38	5.65	4.66	4.09	5.71
H_2O+	.86	1.90	.65	.54	.32	.32	.31	.38	2.53	1.25	.42
H_2O-	.74	.28	.34	.69	.18	.14	.32	.12	.14	2.04	.37
CO_2	.72	.19	3.67	.01	.35	.00	.00	.09	.01	.04	.07
TiO_2	3.43	3.41	1.52	2.17	1.09	.71	.38	.18	.12	.69	.68
P_2O_5	.56	.57	1.35	.71	.35	.32	.13	.02	.00	.18	.13
MnO	.17	.16	.12	.16	.17	.19	.14	.00	.03	.11	.18
SrO	n.d.	n.d.	.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BaO	.06	.05	.24	.10	.13	.20	.04	tr.	tr.	n.d.	n.d.
S	.00	.04	—	.01	.01	.02	.00	.01	n.d.	n.d.	n.d.
SO_3	—	—	.12	—	—	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
F	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.34	n.d.	n.d.
Cl	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.20	n.d.	n.d.
	99.80	99.96	99.79	99.99	99.85	99.81	99.67	99.75	100.00	100.23	100.02
Less O ≡ S		.02				.01					
Less O ≡ Cl									.04		
Less O ≡ F									.15		
	99.80	99.94	99.79	99.99	99.85	99.80	99.67	99.75	99.81	100.23	100.02
Q				2.22	3.00	.66	1.98	24.68	32.97		
or	10.01	10.56	22.09	15.57	31.14	28.94	31.72	33.39	27.27		
ab	32.49	28.82	44.57	36.68	47.16	53.48	54.52	37.75	33.03		
an	22.80	20.57	13.07	23.63	6.12	5.56	2.50	1.95	.46		
ne	—	4.83	—	—	—	—	—	—	—		
di	7.99	6.80	—	5.18	1.73	1.08	1.79	—	.25		
wo	—	—	—	—	—	—	.58	—	—		
hy	2.50	—	.60	2.50	2.11	2.01	—	—	.40		
ol	2.94	8.77	.84	—	—	—	—	—	—		
mt	6.73	5.10	—	5.57	4.87	3.01	4.40	—	1.85		
hm	3.36	—	3.67	1.44	—	2.71	.48	.48	—		
il	6.54	6.54	2.13	4.10	2.13	1.37	.76	—	—		
ru	—	—	.40	—	—	—	—	.16	—		
co	—	—	.20	—	—	—	—	.61	—		
ac	—	—	—	—	—	—	—	.46	—		
ap	1.34	1.34	3.02	1.68	.67	.67	.34	—	—		
cc	1.60	.40	8.31	—	.80	—	—	—	—		
hl	—	—	—	—	—	—	—	—	.35		
f	—	—	—	—	—	—	—	—	.31		

1. Rawls basalt flow (Trb); 2. La Mota gabbro; 3. Plagioclase syenite southeast of Cotter Ranch house; 4. Rawls trachybasalt porphyry (Trbp); Wire Gap; 5. Trachyandesite (Tra), from Hill 5184; 6. Trachyandesite (Tra), top of La Mota Mountain; 7. La Mota syenite; 8. Soda rhyolite from Hill 4778; 9. Rhyolite vitrophyre from Hill 4850; 10. Tuff-breccia, half a mile southeast of BM 4224; 11. Fused tuff-breccia, 2 feet above sample No. 10.

greater content of CaO but also in greater relative amounts of TiO_2, P_2O_5, and BaO. Both rocks show some similarity to the analyzed samples of the Rawls flows, but their relationship to the extrusives is speculative.

Welded Tuff and Breccia

Chemical analyses of two samples selected from near the base and from near the top of a 74-foot bed of tuff breccia between flows of the Rawls basalt are given in Table 5.

The origin of the welded tuff and breccia beds between the Rawls flows is problematical. Because the well-indurated breccia is as much as 74 feet thick, it is improbable that the induration or welding of the rock can be attributed solely to the baking action of the hot lava that covered it. Possibly the material was very hot at the time of eruption and retained sufficient heat to effect the welding.

Variation Diagram

The chemical analyses made for this study are brought together in Table 6 which also contains the norms calculated for the igneous rocks. The analyses of the igneous rocks together with published analyses of rocks from the Terlingua-Solitario region (Lonsdale, 1940, Table 17) and from the Buck Hill area (Goldich and Elms, 1949, Table 10) and eight unpublished analyses of rocks from the Jordan Gap quadrangle are plotted in a silica-variation diagram (Fig. 3). The curves representing the variations of constituents are similar to the earlier curves presented and discussed by Goldich and Elms (1949, Fig. 5).

Structural Geology

Regional Setting

The major structural features of Trans-Pecos Texas have been discussed by Baker (1934, p. 137) and King (1935) and are shown in Figure 4 reproduced from the Structural Map of Texas (Sellards and Hendricks, 1946). The structural history starts with the pre-Cretaceous deformation of the Llanoria geosyncline (King, 1935, fig. 2) and with the development of the northeast-southwest trends in the Paleozoic rocks which are now exposed in the Marathon and Solitario uplifts.

The Cretaceous strata which were deposited on the eroded surface of the Paleozoic rocks were folded in an orogeny (Laramide) which probably began in late Cretaceous time and produced an ancestral range of the present Del Norte-Santiago-Carmen Mountains. West of this range or highland, downwarping formed the Marfa basin (Fig. 4), in which Tertiary volcanic and related rocks accumulated. The Solitario dome was initiated at this time, and probably also the Marathon dome. The folded Cretaceous rocks were eroded and contributed to the lower beds of the Buck Hill volcanic series. The basal Pruett conglomerate rests on the Boquillas limestone (Eagle Ford age) in the Buck Hill quadrangle and on successively younger Cretaceous formations to the south.

Following the accumulation of the Buck Hill volcanic series, 4000–5000 feet thick, in the Green Valley region, deformation in late Cenozoic time resulted from compressive forces which acted on the structural downwarp to produce an upwarp or broad fold in the Tertiary beds. The southwest dip of the Buck Hill volcanic series in the northern two-thirds of the Tascotal Mesa quadrangle is the result of this folding, and these beds form the southwest limb of a large anticlinal structure. The northern part of this structure has been mapped in the Jordan Gap and Buck Hill quadrangle by Goldich and Seward (1948) and Goldich, Elms, and Seward (1949).

Northern Part of Quadrangle

The northern two-thirds of the Tascotal Mesa quadrangle is characterized by the regional dip of 2°–4° S.W. The dip is somewhat steepened along the western boundary, and in the vicinity of Torneros Creek, where the dips are as much as 11°, the steeper inclination of the beds is caused by the Tascotal Mesa fault. A series of parallel normal faults, with small displacement, on Bandera Mesa trends southeast from San Jacinto Mountain. The two most prominent faults are 3 miles long and form a small graben half a mile wide. The displace-

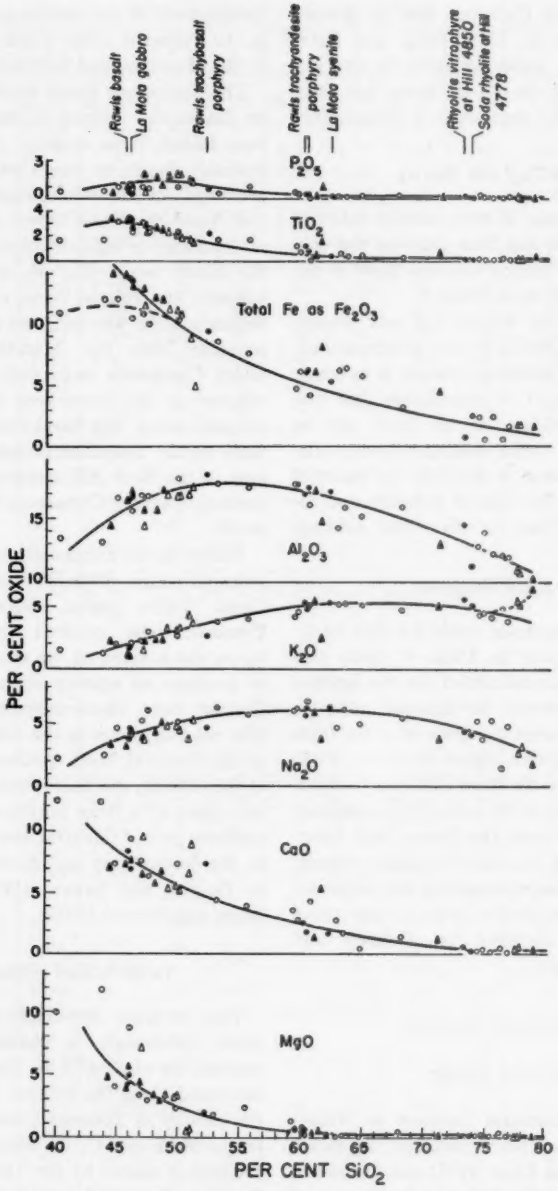

FIGURE 3.—VARIATION DIAGRAM OF IGNEOUS ROCKS FROM THE TASCOTAL MESA QUADRANGLE AND ADJACENT AREAS

Dots represent rocks from the Tascotal Mesa quadrangle; circles, Terlingua-Solitario region (Lonsdale, 1940); solid triangles, Buck Hill area (Goldich and Elms, 1949); open triangles, unpublished analyses of rocks from the Jordan Gap quadrangle.

FIGURE 4.—STRUCTURE OF SOUTHERN TRANS-PECOS TEXAS

From Structural Map of Texas, 3rd ed. by E. H. Sellards and Leo Hendricks, Bureau of Economic Geology, The University of Texas, 1946.

ment is measured in tens of feet. These normal faults are thought to be the result of adjustments accompanying and following the folding, and undoubtedly similar faults occur in Green Valley where they are not easily recognized in the tuff beds.

The northwest structural trend is also displayed in the syenite dikes at Needle Peak and southeast of the Cotter ranch in Green Valley. In contrast the basalt forming The Dike near the northern boundary trends northeast. Minor structures are the result of igneous intrusives that have pierced the Mitchell Mesa tuff flow on Bandera Mesa. Basalt intrusives formed San Jacinto Mountain and La Viuda. Two small syenitic intrusives cut the tuff flow in the southeastern part of the mesa, and the larger forms a trapdoor structure.

Southern Part of Quadrangle

The southern third of the quadrangle is structurally dominated by the Solitario uplift and the complicated peripheral fault system. Lonsdale (1940, p. 1623) has emphasized the role of igneous action in the development of the Solitario, but certain features of the northeast flank of the uplift indicate that the huge dome has a complicated history with more than a single period of uplift and intrusive activity.

The regional dip of the Cretaceous rocks in the southeastern part of the quadrangle is northward, but the dip slope shows minor folds. A domical structure near the southern boundary is indicated in the reversal of dip (Pl. 1). North of the Tascotal Mesa fault, Hill 3837 near the eastern boundary, a dome in the Boquillas formation, was dissected prior to the deposition of the basal Pruett conglomerate. This structure is believed to date back to the Laramide orogeny. In contrast, the domical structure in the Boquillas south of the Holland-Meriwether ranch house is definitely younger and is related to intrusive action in later Tertiary time which can be dated as pre-Rawls basalt. Similar rhyolitic intrusives near by can be dated as post-Mitchell Mesa tuff flow and pre-Rawls.

The largest normal fault is the Tascotal Mesa fault which traverses the quadrangle and extends beyond its boundaries. This fault was mapped and named by Moon in the Agua Fria quadrangle to the east. The Tascotal Mesa fault is a scissor fault with the pivotal area covered by gravel in the central part of the south-central rectangle where the displacement in the Rawls flows is considered relatively small. Westward, the north side is downdropped, and a maximum displacement of 500–700 feet is attained near the west boundary. To the east, the south side is downdropped, and the Mitchell Mesa tuff flow capped by the upper conglomerate–fresh-water limestone facies of the Tascotal is in juxtaposition with the Pruett-Duff beds. The displacement near the east boundary may be of the order of 800 feet.

North of the Tascotal Mesa fault a large fault sets off the basalt hills on the south from Bandera Mesa on the north. The fault is crossed by the Marfa and Lajitas road at a point half a mile south of BM 4207. West of the road a shear zone, 2 feet wide, is filled with calcite. East of the road the displacement on the fault may be as much as 200 feet, but the throw diminishes northwestward, and the fault dies out near Hill 4944.

The area south of the Tascotal Mesa fault is cut into numerous blocks by complicated faults that are best explained as local adjustments to differential movement between the Solitario complex on the south and the gently folded Buck Hill volcanic series on the north. The Solitario fault, mapped and named by Moon in the Agua Fria quadrangle, is half a mile south of and roughly parallel to the Tascotal Mesa fault. It is a strike fault with the principal displacement parallel to the steeply dipping beds of the Boquillas.

Moon estimated that the stratigraphic displacement on the Solitario fault in the Aqua Fria quadrangle is about 2200 feet, but interpretation of the relations in the Tascotal Mesa area, based on the thinning of the Buck Hill volcanic rocks against the Solitario uplift, rules out any displacement of this magnitude and favors a displacement of the order of a few hundred feet.

Just south of the Tascotal Mesa fault near the west boundary, igneous action has domed the volcanic rocks. Farther south, northward dips as high as 20° in the Rawls basalt are the result of a large dome that lies just south of the quadrangle.

Summary Geologic History

The field evidence seems conclusive that the Solitario uplift south of the quadrangle was initiated in late Cretaceous time (Laramide) and was gradually rising during the deposition of the Buck Hill volcanic series.

Igneous rocks are absent or scarce in the basal Pruett conglomerate. If, as earlier writers have suggested, the Solitario was domed up by a large intrusive, this intrusion must have been at depth, and igneous rocks in appreciable quantity did not reach the surface. However, the possibility that the initial stage in the development of the Solitario was a wholly structural deformation unrelated to igneous intrusion cannot be dismissed. In contrast with the basal Pruett conglomerate, the conglomerates in the Duff and Tascotal formations contain a variety of igneous types, and in many areas certain cobbles and boulders can be traced to near-by igneous masses, and so date the intrusives.

The Buck Hill volcanic series thins and wedges against the flank of the Solitario uplift. The wedging is accompanied by pronounced changes in lithologic characters. As the tuff beds in the Green Valley area are traced southward they interfinger and merge with lentils of coarse conglomerates and fresh-water limestone beds that were derived by erosion and weathering of the Solitario complex. The tuff beds in the Tascotal Mesa quadrangle commonly are calcareous due to the available source of carbonate in the exposed Cretaceous formations. Local ponding explains the fresh-water limestone beds in the Duff and in the Tascotal. Farther north, in the northern parts of the Buck Hill and Jordan Gap quadrangles which were relatively removed from exposed Cretaceous rocks, the Duff contains little calcium carbonate (Goldich and Elms, 1949, p. 1160).

The accumulation of the thick succession of Tertiary tuff beds and related sediments was not continuous and the tuff locally was eroded as is indicated by the scour-and-fill structure at the base of the thick bed of conglomerate in the upper part of the Duff formation. In the upper Duff beds, in the scarp of Bandera Mesa, are also found the first or oldest basalt flows exposed in the quadrangle. These flows were followed shortly by the extrusion of the Mitchell Mesa tuff flow. Light-colored sandy tuff beds were deposited on the eroded hummocky surface of the tuff flow over most of the northern two-thirds of the quadrangle, although locally conglomerate beds mark the base of the Tascotal formation.

The most southerly remnant of the Mitchell Mesa tuff flow is west of Hill 4850, 1½ miles north of the south boundary. The tuff flow probably extended south of this point originally, but it was removed by vigorous erosion that followed a period of uplift and intrusion during which the rhyolitic masses in the southeastern part of the quadrangle were emplaced. One small remnant of the beds that rested on the Mitchell Mesa tuff at the time the rhyolite was intruded is mapped on the southern end of Hill 4850 at an altitude of 4700 feet.

The tuff and breccia into which the rhyolite magma was intruded was easily and quickly eroded. The rugged topography was favorable for the accumulation of local coarse conglomerates to which the high peaks of rhyolite contributed heavily. By this time, the Solitario dome had been breached and eroded extensively so that the Paleozoic formations supplied material that was transported northward and incorporated in the upper Tascotal conglomerate. Large, angular to subrounded boulders of Caballos novaculite and black chert suggestive of the Maravillas formation are conspicuous in the conglomerate.

The upper sandstone and conglomerate beds of the Tascotal formation are succeeded by the flows of the Rawls basalt. The flows overrode the conglomerate at the southern edge of the quadrangle and came to rest on the upturned and eroded Devils River limestone. Basaltic intrusives such as San Jacinto and La Viuda in the north and the two small plugs and dike in the southeastern part of the area may be related to the flows, but the main bulk of the lavas, the trachybasalt porphyry and the trachyandesite porphyry flows, appear to have moved into the quadrangle from the southwest.

A later period of intrusive activity followed the extrusion of the Rawls lavas, and syenitic dikes cut the flows in the southwest corner in the La Mota area. Possibly the syenitic dikes in Green Valley and the small plug on Bandera

Mesa are related to this period of activity, but there is no way of correlating the intrusives.

The Buck Hill volcanic series was folded, probably in late Tertiary time when the northwest structural trends were developed in Trans-Pecos Texas. The folding was accompanied by regional uplift, and large-scale faulting resulted. Minor faults in the northern part of the area trend northwest and are closely related to the axis of folding. The major faulting in the southern part is believed to be due to differential movements in which the Solitario complex acted, more or less, as a positive structural element about which a complicated fault pattern was developed.

Volcanic extrusives younger than the Rawls flows do not occur in the quadrangle, and search for such rocks is best directed to the region to the southwest. Younger sediments include gravels and other alluvial deposits. Gravel-capped pediments occur at different levels, and in Green Valley the older pediments are now being actively eroded.

References Cited

Adkins, W. S., 1932, The Mesozoic systems in Texas, Part 2, The geology of Texas, Volume 1, Stratigraphy: Texas Univ. Bull. 3232, p. 239–518.

Baker, C. L., 1934, Major structural features of Trans-Pecos Texas, Part 2, The geology of Texas, Volume 2, Structural and economic geology: Texas Univ. Bull. 3401, p. 137–214.

Clarke, F. W., 1904, Analyses of rocks from the laboratory of the United States Geological Survey: U. S. Geol. Survey Bull. 228, 375 pages.

Eifler, G. K., Jr., 1943, Geology of the Santiago Peak quadrangle, Texas: Geol. Soc. America Bull., v. 54, p. 1613–1644.

—— 1951, Geology of the Barilla Mountains, Texas: Geol. Soc. America Bull., v. 62, p. 339–354.

Fenner, C. N., 1923, The origin and mode of emplacement of the great tuff deposits of the Valley of Ten Thousand Smokes: Natl. Geog. Soc. Contri. Tech. Papers, no. 1, 74 pages.

—— 1948, Incandescent tuff flows in southern Peru: Geol. Soc. America Bull., v. 59, p. 879–893.

Gilbert, C. M., 1938, Welded tuff in eastern California: Geol. Soc. America Bull., v. 49, p. 1829–1862.

Goldich, S. S., and Elms, M. A., 1949, Stratigraphy and petrology of the Buck Hill quadrangle, Texas: Geol. Soc. America Bull., v. 60, p. 1133–1182.

Goldich, S. S., and Seward, C. L., 1948, Green Valley-Paradise Valley field trip: Midland, Tex., West Texas Geol. Soc. Guide Book, p. 10–36.

Goldich, S. S., Elms, M. A., and Seward, C. L., 1949, Green Valley-Paradise Valley field trip: Midland, Tex., West Texas Geol. Soc. Guide Book, p. 10–36.

Huffington, R. M., 1943, Geology of the Northern Quitman Mountains, Trans-Pecos Texas: Geol. Soc. America Bull., v. 54, p. 987–1046.

King, P. B., 1935, Outline of structural development of Trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 221–261.

Lonsdale, J. T., 1940, Igneous rocks of the Terlingua-Solitario region, Texas: Geol. Soc. America Bull., v. 51, p. 1539–1626.

Mansfield, G. R., and Ross, C. S., 1935, Welded rhyolitic tuffs in southeastern Idaho: Am. Geophys. Union Trans., p. 308–321.

Marshall, P., 1935, Acid rocks of the Taupo-Roturua volcanic district: Royal Soc. of New Zealand Trans. and Proc., v. 64, p. 323–336.

Moon, C. G., 1953, Geology of the Agua Fria quadrangle, Brewster County, Texas: Geol. Soc. America Bull., v. 64, p. 151–196.

Ross, C. P., and Cartwright, W. E., 1934, Preliminary report on the Shafter Mining District, Presidio County, Texas: Texas Univ. Bull. 3401, p. 573–608.

Scott, Gayle, 1939, Cephalopods from the Cretaceous Trinity group of the south-central United States: Texas Univ. Bull. 3945, p. 969–1106.

Sellards, E. H., and Hendricks, Leo, 1946, Structural map of Texas, 3d ed.: Bur. of Econ. Geology, Univ. Texas.

Smith, J. F., Jr., and Albritton, C. C., Jr., 1941, Solution effects on limestone as a function of slope: Geol. Soc. America Bull., v. 52, p. 61–78.

Udden, J. A., 1904, The geology of the Shafter silver mine district, Presidio County, Texas: Texas Univ. Bull. 24 (Min. Survey ser. Bull 8), 60 pages.

—— 1907a, Report on a geological survey of the lands belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande embayment in Texas: Augustana Libr. Pub. no. 6, p. 51–107.

—— 1907b, A sketch of the geology of the Chisos country, Brewster County, Texas: Texas Univ. Bull. 93 (Sci. ser. Bull. 11), 101 pages.

Vaughan, T. W., 1900, Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, p. 76–81.

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Short Notes

ISOTOPIC COMPOSITIONS OF QUATERNARY LEADS FROM THE PACIFIC OCEAN

BY CLAIRE C. PATTERSON, EDWARD D. GOLDBERG, AND MARK G. INGHRAM

Knowledge of the variations of the isotopic compositions of marine leads with time will provide the basis for further studies concerning general problems of the evolution of the earth's crust and specific problems of the histories of localized sedimentary bodies. Important aspects of the acquisition of this knowledge are: (1) factors in the processes of weathering and transport to the oceans which may result in selective enrichment or depletion of the isotopes of lead in oceanic waters; (2) the form in which lead exists in oceanic waters and the influence this may have upon the factors of mixing and of incorporation into sedimentary deposits by the different mechanical, electrochemical, and biological mechanisms; and (3) obtaining samples from marine sedimentary deposits which contain lead representative of the marine hydrosphere and which has not been altered by mixing with leads of different isotopic compositions from other sources after these deposits were formed.

Preliminary experiments were carried out in which carrier-free Pb^{210} tracer was added to samples of near-shore sea water, and these samples, after standing for about 10 hours, were filtered through "Type HA Millipore"[1] filters which can remove all particulate matter greater than 0.4 μ in diameter. Vessels of polyethylene were used to prevent lead from being absorbed by the walls of the containers. About 10 per cent of the Pb^{210} could be recovered by filtration at the rate of 250 ml per minute atmosphere through normal filters. About 80% of the Pb^{210} could be recovered by filtration at the rate of 1 ml per minute atmosphere through filters clogged with iron or manganese hydrosols. E. Goldberg and M. Lewis (unpublished manuscript) have shown that iron exists in sea water mainly as a hydrosol. It is evident that a major fraction of the lead in sea water is associated with hydrosols.

The concentrations of lead in a sample of a red clay, a manganese nodule, and a lower Pleistocene limestone, all from the Pacific Ocean, have been determined spectrophotometrically, using Pb^{210} for yield corrections, and by the isotope dilution method. The isotopic compositions of the isolated leads were determined in a mass spectrometer by using surface ionization methods (Patterson, 1951; Tilton *et al.*, Manuscript). The concentrations of iron and manganese in these samples were determined spectrophotometrically. The values for lead, manganese, and iron are listed in Table 1.

A description of the Lomita marl has been given by Woodring, Bramlette, and Kew (1946), and the sample used here was collected by Dr. G. J. Neuerburg, of the U. S. Geological Survey, Pasadena, from the Lomita Quarry in the Palos Verdes Hills. Emiliani and Epstein (1953) have shown that the temperatures of formation have been recorded by the fossils in this material, indicating that the lead which was isolated from the marl probably has not been contaminated by lead from other sources in the vicinity. However, the fractions of this lead that originate from materials of organic and of inorganic origin in the marl are as yet unknown.

The manganese nodule was collected at lat. 19°40′N., long. 168°32′W. (Scripps Institution

[1] Lovell Chemical Co., Watertown, Mass.

of Oceanography Midpac Station 25). The complete nodule weighed about 25 grams. The air-dried sample contained 18.3 per cent water obtained at 110°C, and a 12.1 per cent residue lead than that in the acid-soluble fraction of the marl which was formed in the near off-shore waters. If such is the case, the isotopic compositions of a number of marine leads, obtained

TABLE 1.—IRON, MANGANESE, AND LEAD IN MARINE SAMPLES

Sample	Iron (Wt%)	Manganese (Wt%)	Lead (ppm)	Lead Composition (atomic ratios)*		
				Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}
Lomita Marl†	0.031	0.0001	0.31	19.27	15.61	39.40
Manganese Nodule**	17.3	18.1	3,450.	18.91	15.69	38.68
Red Clay††	6.31	0.78	35.2	18.95	15.76	38.92

* The ratios have an assigned absolute error of 1%.

† Dilute acid soluble fraction. Insoluble residue = 1.5%.

** Acid-soluble fraction of composite sample, dried at 110°. Scripps No. MP 25 F2.

†† Dried at 110°, Scripps No. MP 13 38-41″.

insoluble in hydrochloric acid, consisting of a spongy network of nearly pure silica.

The red clay was collected at lat. 9°8′N., long. 144°25′W. (Scripps Institution of Oceanography Midpac Core No. 13). The sample was taken 38 to 41 cm from the top of the core. The moist specimen contained 70.4 per cent water obtained at 110°C. Lead was isolated from the entire sample.

It is believed that the similarity of the Pb/Mn ratios and the dissimilarity of the Pb/Fe ratios in the manganese nodule and the red clay indicate that a major amount of the lead in oceanic waters may be absorbed on manganese hydrosols. The compositions of the leads in the manganese nodule and red clay are similar, and both are different from that obtained from the acid-soluble fraction of the marl. This difference may indicate that the red clay and the manganese nodule, formed mainly in the sedimentary deposits of the deeper ocean, contain lead which is more nearly representative of a mean oceanic from a relatively few samples in carbonate rocks of different ages, will have an unknown variation from an assumed direct correlation. This difference may, however, result from another cause. The lead from the acid-soluble fraction of the marl may be contaminated by the partial decomposition of some relatively old minerals in the insoluble residue which contain a local, or nonrepresentative lead.

REFERENCES

Emiliani, C., and Epstein, S., 1953, Temperature variations in the Lower Pleistocene of Southern California: Jour. Geology, v. 61, p. 171.

Patterson, C., 1951, The isotopic compositions of trace quantities of lead and calcium: Atomic Energy Comm. Rept. AECD-3180.

Woodring, W., Bramlette, M., and Kew, W., 1946, Geology and paleontology of Palos Verdes Hills, California: U. S. Geol. Survey Prof. Paper 207.

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ABSTRACTS OF PAPERS SUBMITTED FOR THE NOVEMBER MEETING IN TORONTO, CANADA, NOVEMBER 9–11, 1953

URANIUM CONTENT OF THE LAVAS OF LASSEN VOLCANIC NATIONAL PARK, CALIFORNIA

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Ninteen samples of volcanic rocks from Lassen Volcanic National Park have been analyzed for U, Na, K, and Ca. In addition, the alpha activities were measured with scintillometers. U and K correlate positively, indicating that both tend to be enriched as differentiation proceeds toward more siliceous lavas. In the samples studied the U is enriched about fourfold, while the K is enriched about threefold. The correlations with Ca, Na, and total K + Na are less well defined than the K correlation. The correlation between K and alpha particle activity under standard conditions is rather well defined.

The correlation between alpha particle activity and U is not well defined when all samples are included. However, the samples that are furthest from the main trend may be considered special cases—*e. g.*, mud flows and rocks that were probably partially weathered and thus leached of part of their U. The main trend in the U content vs. alpha particle activity indicates that the Th/U ratio did not shift significantly during the differentiation of the Lassen lavas.

URANIUM CONTENT, ALPHA PARTICLE ACTIVITY, AND K_2O, Na_2O, CaO ANALYSIS OF OBSIDIANS, PITCHSTONES, AND TEKTITES

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Seventy-four glassy rocks, including obsidians, pitchstones, tektites, and possible tektites have been analyzed for uranium fluorimetrically. Alpha activities have been measured with scintillometers. K_2O, Na_2O, and CaO have been determined on the flame photometer. The indices of refraction have also been measured. About half the samples are from the United States. The thermoluminescence of several samples was also measured, but no thermoluminescence was detected except in one obsidian from Ascension Island.

The uranium contents range from 0.77 ppm in an obsidian from Shizuoka Prefecture, Japan, to 16 ppm in an obsidian from Liparii, Italy. Few of these obsidians have as much as 0.50 per cent CaO. A plot of alpha particle activity under standard conditions vs. uranium content has little scattering from linearity. This linearity indicates that the Th/U ratio is rather constant in the obsidians measured. Several geochemical interpretations of this linearity are advanced.

LOGNORMAL DISTRIBUTION OF THE ELEMENTS

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The statistical nature of the distribution of Li, K, Rb, Cs, Ga, Sc, V, Co, Cr, Cu, F, Pb, La, and Zr in many specimens of two specific rock types—granite (New England and Canada) and diabase (Ontario, Canada)—has been examined. Distribution *appears* to be normal only when dispersion is small, as in the examples of Ga (granite and diabase) and Sc, V, and Co (diabase only). Skewness, however, increases regularly with increase in the amount of dispersion and is extreme for Cr (granite and diabase) and Sc, V, and Pb (granite only). All elements, irrespective of whether they have a small or

large dispersion, show a distribution which is *lognormal*, or at least closely approaches it. An assumption of normal distribution leads to completely erroneous predictions about the prevalence of various concentrations of an element, if its dispersion is large—in fact, the occurrence of some granite with negative concentrations of V, Sc, Pb, and Cr is predicted on the basis of such an assumption.

An element may show a totally different degree of dispersion in granite and diabase. For example, dispersion of Sc and V is small in diabase but extreme in granite; on the other hand, dispersion of Rb and K is small in granite but moderately large in diabase.

These conclusions are based on quantitative spectrochemical determinations, each calibrated with standard rocks.

UNIQUELY OLD PRECAMBRIAN AGE DETERMINATIONS AND SOME GEOLOGICAL IMPLICATIONS

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The comparatively large number of Precambrian age determinations now available provides conclusive evidence that several, though by no means all, of the large basement shield areas are represented by at least one pegmatite group that is uniquely old. Age determinations from each of these areas, notably southeastern Manitoba, Russian Karelia, Southern Rhodesia, and Varuträsk, Sweden, are compared mainly with the purpose of throwing light on some problems of paramount geological interest. For example, the possibilities (1) that some of the shield areas, Brazil and Australia for example, are younger than others, and (2) that the events which brought about the formation of each of the uniquely old pegmatites may have taken place contemporaneously.

COMPARISON OF THE AGES OF SOME PRECAMBRIAN ROCKS MEASURED BY DIFFERENT RADIOACTIVE DECAY SCHEMES

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The large increase in sensitivity of the modern mass spectrometer with the attendant diminution of the size of sample required for isotope analysis, coupled with the availability of stable isotope tracers, had made possible precise determination of the ratios of parent to daughter isotope of many additional mineral species. These minerals are characterized by relatively low concentrations of the parent element (a few tenths to a few hundredths per cent) and nearly complete rejection by the mineral of any daughter element present in the rock. Examples of such minerals are zircon, sphene, and apatite for U and Th parent elements, and biotite, phlogopite, and orthoclase for Rb and K. It is seen from this list that the possibility of dating a granite by two or more methods is now very real, and data will be presented showing the comparison of the determinations made on granites (and their associated pegmatites where possible) from a few Precambrian localities. In developing the methods, the ages of many other Precambrian rocks were determined.

UPPER DEVONIAN GEOLOGIC HISTORY IN STETTLER AREA, ALBERTA, CANADA

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The Stettler area in south-central Alberta constitutes 7000 square miles and extends from Townships 32 to 42 and from Ranges 17 to 28, West of 4th Meridian.

Normal marine and fragmental limestones with interbedded argillaceous limestone, and some dolomites and anhydrites form the sediments of Upper Devonian basal unit, Beaverhill Lake formation, in the area. These strata, and the overlying normal marine and fragmental limestones of the Cooking Lake member, were deposited during unstable shelf conditions. Biohermal reef growth commenced approximately at the end of deposition of Cooking Lake along loci of shallower water or shoals. Stromatoporoids and other organisms built vertical reef structures according to the subsidence rate which determined the water-depth conditions at the site. Shale was deposited in part contemporaneously with reef growth. Biohermal growth continued until the close of Woodbend time when more stable tectonic conditions inhibited further upward growth of reefs. Commencement of these shelf conditions later permitted development of laterally growing dolomitized Nisku reefs (biostromes). Development of complex shoal patterns caused variable evaporite precipitation, which commenced earliest in intershoal areas. At the end of Winterburn time, subaerial or near subaerial conditions are indicated by green and red clastics of the Calmar member. Evaporite deposition including salt characterized Devonian deposition for most of the remaining Devonian time. Normal marine limestone beds, in part dolomitized, at the top of Devonian sections indicate restoration of normal marine sedimentation in pre-Mississippian time in the Stettler area.

RELATIONSHIPS OF RADIOACTIVE ELEMENTS IN THREE CORES FROM THE GULF OF MEXICO

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Three cores, 160 to 280 cm. long, from the center of the Gulf of Mexico, were sampledand analyzed. Total radium content was determined by separate measurements of fixed radon released by fusion, and of emanating radon. Contents of manganese, iron, and some minor constituents were measured by spectrograph. The U. S. Geological Survey measured uranium by the fluorimetric method. In addition, grain-size distribution was determined, and F. B. Phleger has published an analysis of the Foraminifera found in these cores.

Manganese and radium content vary together with major fluctuations. Variations in uranium content are smaller and appear to have no relation to the changes of radium and manganese. Proportion of emanating radon is high and variable in the upper 30 cm. and drops to a low constant value of about 20 per cent throughout the rest of the cores. The results suggest that ionium unsupported by uranium persists to the bottoms of all three cores without much change.

The following inferences are drawn. The sediments have not been disturbed and may be stratigraphically correlated over a distance of 200 miles. At a depth of 25 cm. in all three cores there still exists an amount of unsupported radium that has not decayed for a time exceeding one radium half-life. Thus the rate of deposition in this part of the core is not less than 18 cm. per 1000 years.

EMERALD, FEENEY, AND DODGER TUNGSTEN ORE BODIES, SALMO, BRITISH COLUMBIA

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The scheelite ore bodies occur within limestone and skarn country rock and are localized where such beds conformably overlie argillite and form trough structures by contact with intrusive granite.

Faulting is found along the main granite contact, and minor faults which strike subparallel to the troughs have exercised a definite structural control. It is believed that mineralization, arising from deep within the granite, was distributed by quartz-tourmaline veins and siliceous veins traversing breccia zones and faults. Tungsten solutions were also concentrated at nodal points by offshoot dikes of granite and pegmatite running out from the granite into the beds of limestone and skarn.

Four distinct types of host rock are recognized: skarn, limestone, quartz, and greisenized granite. Pyrrhotite and biotite are generally present in the first three types, and a close association is shown between scheelite and quartz in all four types. Most of the scheelite is finely disseminated and distinguished only by use of the ultra-violet lamp. A little powellite and molybdenite appear close to the underlying argillite and at the granite contact.

The ore bodies are lenticular and tend to thin and splay out on the flanks. They are contact metamorphic in origin. In close proximity to the ore zones the granite is greisenized, and tourmaline is conspicuous.

Hydrothermal action is indicated by sericitization of the feldspars and chloritization of the biotite. Two generations of quartz are indicated, and there may be two generations of scheelite.

Major production to date has come from the Emerald trough which is over 4000 feet in length.

GEOLOGY OF ISABELA (ALBEMARLE) ISLAND, ARCHIPIÉLAGO DE COLÓN (GALÁPAGOS)

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Isabela, westernmost and largest island of the Galápagos, 700 miles from Guayaquil, Ecudaor, and with center about 0° 30′ S. Lat., 91° 00′ W. Long., resembles a letter "J", 51 miles in widest, 82 miles in longest dimensions. It is entirely volcanic, and several of its five shield volcanos, 4–7 miles in diameter and 3800–5100 feet high at their rims, have erupted during this century. All 400 inhabitants live on Isabela's southern shore. Of much biologic interest, it was visited by Darwin (1835), Beebe (1923), and others. Its geologic features were detailed only by Chubb and Richardson (1933). Available soundings suggest linkage of the Galápagos to Central America rather than Ecuador.

In January–March (the rainy season), 1953, four geologists explored the five calderas whose confluence built the island, and several smaller cones. The country rock is lava, scoria, and tuff—mainly basaltic. No rock seen is more acidic than andesite. Lava chiefly constitutes the lower, relatively barren slopes of the island; the upper, grassy or lightly tree-clad parts are more scoriaceous to pumiceous, but late flows abound, especially in the craters. Shelly sands appear on protected beaches.

Striking volcanic features include spatter cones, slickensided flows, rifts, crevasses, solfataras, fumaroles, and unusually linear eruptions—many visible on aerial photographs. Breaching of cones follows local patterns—*e.g.*, toward the south on the southeasterly side of Isabela. Sulfur deposits are associated with bleaching and vents emitting steam, hydrogen sulfide, and sulfur dioxide. Apparently oxidation of the hydrogen sulfide yielded steam and sulfur.

CAVITATION AS A GEOLOGICAL AGENT

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Cavitation is the formation and collapse of bubbles of vapor in a fluid stream. Formation of the bubbles is caused by a local reduction in absolute pressure to the vapor pressure of the fluid; collapse of the bubbles is caused by a subsequent pressure increase. The pressure reduction is usually caused by an increase in local velocity due to an irregular streamline configuration (Bernoulli's Theorem). The mechanism is important because the powerful shock waves initiated by the collapse (*i.e.*, implosion) of the bubbles cause rapid erosion of even the hardest materials. For example, one case is cited in which cavitation eroded a maximum depth of 18 inches of concrete in a dam spillway in 23 hours.

The mechanism is examined in reference to open-channel stream erosion with water as the fluid. The following variables are treated either quantitatively or qualitatively: vapor pressure, absolute pressure, temperature, velocity, viscosity, surface tension, concentration and solubility of dissolved gases, streamline configuration, wall roughness, fluid compressibility, rate of attainment of equilibrium

between the liquid and vapor phases, and the stream slope. The principles involved are applicable to other fluids in either open-channel flow or, with minor modifications, closed-channel flow.

Cavitation is evidently an important agent in the erosion of rock by glacial meltwaters and by many high-velocity streams. The same mechanism is suggested as a possible factor in the development of tectonic features related to the movement of magmas and ore-forming solutions at high temperatures and high vapor pressures.

FURTHER DATA ON THE ISOTOPIC COMPOSITION OF COMMON LEAD

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The isotopic composition of about 50 lead minerals of worldwide distribution has been obtained by mass spectrometric analysis. The range in composition lies within the extremes reported in the literature for common lead. The results indicate a maximum variation of about 4 per cent in the Pb^{207}/Pb^{206} ratio for minerals from the same metallogenic province.

It appears that in most areas a few isotopic analyses of common lead samples will be sufficient to define the abundances to use in correcting a radiogenic lead for contamination by common lead. This in turn virtually eliminates this source of uncertainty in uranium-lead age measurements.

In order to define the age of the earth more accurately, it is necessary to obtain a still larger number of istotopic analyses of common lead from dated localities.

CALLAGHANITE, A NEW MINERAL

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Studies of small, azure-blue crystals from the working pits of the Gabbs Refractories, Inc., Gabbs, Nevada, lead to the description of a new hydrated basic copper, magnesium, calcium carbonate, $Cu_4Mg_4Ca(OH)_{14}(CO_3)_2 \cdot 2H_2O$. The mineral is named callaghanite after Dr. Eugene Callaghan, Director, New Mexico Bureau of Mines and Mineral Resources, in recognition of his geological work on magnesite deposits. The mineral occurs near peridotite dikes intrusive into magnesite and dolomite.

X-ray studies by Weissenberg and precession methods showed callaghanite to be monoclinic; space group either C_s^4—Aa or C_{2h}^6—$A2/a$; and cell dimensions $a_0 = 8.24$ Å, $b_0 = 11.80$ Å, $c_0 = 10.06$ Å, $\beta = 107°18'$. Elements calculated from x-ray data are: $a:b:c = 0.6983:1:0.8525$; $p_0:q_0:r_0 = 1.2209:0.8140:1$; $\mu = 72°42'$; $p_0' = 1.2788$, $q_0' = 0.8525$, $x_0' = 0.3115$. The unit cell content is 2.

Crystal forms present are {111}, {$\bar{1}$11}, {221}, and {$\bar{2}$21}. Elements calculated from goniometric data are: $a:b:c = 0.7252:1:0.8504$; $p_0:q_0:r_0 = 1.2168:0.8092:1$; $\mu = 72°5'$; $p_0' = 1.2788$, $q_0' = 0.8504$, $x_0' = 0.3094$.

Optical data are: $n_X = 1.559$, $n_Y = 1.653$, $n_Z = 1.680$; $2V = 55°$; optically (−); $Z \wedge c = 18$; pleochroic in blue with absorption $Z > Y > X$; $r > v$, strong.

Cleavages are {111} and {$\bar{1}$11}, perfect; brittle; hardness is 3–3½; transparent; habit, pyramidal. Calculated specific gravity is 2.78; measured 2.71.

ALTERATION ASSOCIATED WITH ORE AT GASPE COPPER MINES

A. M. Bell and F. J. Scott

The geology of the copper deposits now being developed by Gaspe Copper Mines in the Gaspe Peninsula is summarized in this paper with particular attention to metamorphism in the host rocks associated with ore replacement.

The ore occurs in faulted and gently folded Paleozoic sediments and seems to derive from a buried stock of granite. The best ore body is a replacement in a limestone bed and lies updip from the intrusive. The deeper end of this ore approaches within half a mile of the granite, and the upper end is 1¼ miles away. Two types of alteration are in evidence. One type is a general metamorphism of a block with a surface extent of 2 square miles that has bleached the rocks and developed silicates with only minor changes in chemical composition. This alteration is earlier, has no direct connection with ore replacement, and seems to be an effect of heat from the granite. Another type of alteration is intimately connected with ore and involves a decided change in chemical composition. This alteration seems to be produced by solutions, a late phase of which accomplished ore replacement. The limy beds have been converted to silicates by the addition of silica and the loss of lime, while the less limy rocks have been silicified. Ore coincides with the skarn alteration in those areas in which some unreplaced calcite remains in the silicate rock. These areas are in the portions farthest from the intrusive center and on the flanks of the skarn.

The Gaspe ore is a hydrothermal replacement whose further study should throw light on the controls and temperatures of deposition of other deposits occurring in sedimentary rocks.

DEVONIAN OSTRACODE FAUNA FROM NEVADA

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A varied and abundant fauna of silicified ostracodes has been found in the Mount Lewis quadrangle in eastern Nevada. According to James Gilluly the formation in which the ostracodes occur is predominantly clastic. They are found in thin beds of fine-grained sandstone with calcareous cement and are associated with *Tentaculites* sp., conodonts, and fragments of brachiopods, trilobites, and bryozoans. To date, 18 genera have been identified, of which 6 (*Proplectrum, Abdiloloculina, Arcyzona, Chironiptrum, Subligaculum, Sulcicuneus*) have been described by R. V. Kessling from the lower part of the Traverse group in Michigan. The other 12 genera are also represented in the lower part of the Traverse and other strata of Middle Devonian age. Several new genera are present in the fauna. On the basis of the ostracodes, and of conodonts identified by Wilbert Hass, the formation containing them is believed to be Middle Devonian and is presumably equivalent to some part of the Nevada limestone, although no precise correlation can be made as yet. This is believed to be the first recorded occurrence of Middle Devonian ostracodes in the Great Basin region.

RED DRIFT OF THE MANISTEE MORAINE IN MICHIGAN

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On the basis of apparent red coloration in the glacial drift of the Manistee moraine recent investigators have proposed to correlate this deposit with the Valders in Wisconsin, thus relating the outer main ridge of the Port Huron moraine to the Cary substage.

Field studies in that portion of the moraine extending from Manistee to Traverse City provide evidence that boulder-sand surficial drift in the moraine does not possess the distinctively deep red color that characterizes the Valders in the type locality. Generally speaking, the drift is predominantly brown to grayish brown with patches of red clay protruding through to the surface in widely scattered areas.

Beneath the relatively thin veneer of Manistee drift, apparently deposited during the most recent episode of ice adjustment, is a firmly compacted, highly calcareous, block-jointed, chocolate-brown clay variously exposed in cuts to altitudes ranging from 700 to 1000 feet. This material, leached to an average of 36 inches, weathers into deep-red mealy clay that assumes gumbolike characteristics when saturated.

The contact of the brown with the underlying blue-gray drift is not sharp, but rather marked by interfingering in the joint planes with no preceptible change in calcareous content.

It is the opinion of the writer that this undermass of heavy clay drift represents the product of Cary deposition which was overridden by the ice during its most recent advance to form the mantle of bouldery till that makes up the bulk of the composition of the Manistee moraine in the area.

NATURE OF CRYSTALLIZATION OF METAMICT MINERALS

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In recent years there has been an increasing interest in the study of metamict minerals with regard to their origin, identification, and possible use as geologic age indicators.

Many of these noncrystalline minerals have been crystallized by heating to comparatively high temperatures, and various workers index the x-ray powder patterns of these heated specimens under the assumption that this crystalline material is a re-formation of the mineral as originally deposited or crystallized in the rock.

The writer points out that recrystallization to the original structure of the metamict minerals is the exception rather than the rule. Likewise, data will be presented to show that the temperature and type of crystallization of some of these minerals are dependent upon their present state of metamictization and upon the present composition which may or may not be their original composition.

It also will be shown that certain related "stable" minerals will dissociate when subjected to the temperatures at which some metamict minerals crystallize.

PRE-HAMILTON DEVONIAN STRATIGRAPHY, SOUTHWESTERN ONTARIO, CANADA*

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The pre-Hamilton Devonian section, exposed in the northwesterly trending belt from Fort Erie to Goderich, Ontario, is discussed in ascending geological order.

The Oriskany sandstone, characterized by *Acrospirifer murchinsoni*, is limited to a small area in the Niagara Peninsula. The sandstone unconformably overlies the Silurian and is unconformably overlain by the Bois Blanc formation.

The Bois Blanc formation is divided into a basal sandy member, the Springvale, which outcrops only in the Niagara area, and an upper more widespread and thicker cherty limestone member. Both members contain an abundant lower Onesquethau fauna typified by *Amphigenia elongata*.

The Detroit River group, locally divisible into the Lucas and Amherstburg formations, is discussed as a southern limestone facies and a northern facies, consisting of bedded dolomites, minor limestone, algal biostromes, and Stromatoporidae bioherms with associated clastics. The fauna of the southern facies, which contains typical Detroit River forms like *Prosserella lucasi*, is strikingly different from that of the northern facies. The Detroit River group and Bois Blanc formation are not believed to be separated by an important unconformity.

The Columbus limestone, characterized by *Paraspirifer accuminatus*, unconformably overlies the Detroit River group. Northward the formation overlaps the northern extension of the Findlay arch.

The Delaware formation is divisible into a lower clastic limestone member, outcropping in the northern area, and a more widespread, thicker, upper shaley limestone member. The members are gradational and contain a *Brevispirifer lucasensis* fauna typical of the Dundee and Delaware formation of Michigan and Ohio.

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STRUCTURAL AND DECREPITATION FEATURES OF THE GOLD MINERALIZATION AT THE O'BRIEN MINE, QUEBEC*

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Quartz veins of distinctive structural pattern and characteristic wall-rock alteration form the environment of gold deposition at the O'Brien mine. Fracturing and shattering of vein quartz afforded minute openings for migration of auriferous solutions, and the late gold was concentrated in, or near, structures favoring such brecciation of vein quartz. The ore shoots have almost vertical pitch, with a great pitch length in comparison to stope length.

The observed relationships of minor-scale fracturing of vein quartz to gold deposition and to planes of secondary liquid inclusions form the basis for this extensive study of vein quartz. The decrepitometric data for 1000 quartz samples indicates relationships between liquid inclusion decrepitation and distribution of ore values. Auriferous vein quartz is characterized by decrepitation temperatures from 75°C to 120°C, whereas barren quartz starts to decrepitate above 130°C. Trend lines of low decrepitation temperatures correspond to ore chimneys. It is suggested that barren sections of quartz veins have not been reworked during the gold stage and, consequently, do not show low-temperature decrepitation, which appears to be due to characteristic liquid inclusions trapped in intra-mineralization fractures of vein quartz.

ISOTOPIC ABUNDANCES IN ROCKS AND METEORITES

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Hydrogen, nitrogen, and carbon isotopes were studied in a number of rocks and meteorites to clarify some aspects of the problem of the loss of volatiles from the planetary system and of the origin and formation of the atmosphere.

Hydrogen isotopes were analyzed in the water contained in stony meteorites and igneous rocks: the abundance of deuterium in these samples is explainable with single-stage fractionation processes. No nuclear or multiple fractionation processes seem to be involved, and therfore one can conclude that the abundance of hydrogen isotopes does not change remarkably through the planetary system, except for the sun where the deuterium was consumed by nuclear reactions. Particularly interesting are the carbonaceous chondrites, which contain up to 10 per cent of water and show a minimum of contamination by terrestrial water. The percentage difference in the D/H ratio in these meteorites ranges from -5 per cent to $+20$ per cent as referred to the average ocean water. Carbon isotopes were also analyzed in these meteorites; they show a high C^{13} content with respect to the average on the earth and to the ordinary chondrites. Nitrogen isotope ratios have been measured in rocks. Amounts of nitrogen of 0.1 cc are easily extracted and analyzed with the developed technique. N^{15}/N^{14} variations of some per cent with respect to the atmospheric nitrogen were found.

SILURIAN STRATA OF THE NIAGARA ESCARPMENT, ONTARIO†

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Strata exposed in the Ontario portion of the Niagara escarpment are assigned to three groups. The Lower Silurian Cataract group, representing a complete sedimentary cycle from transgression to regression, consists of the Whirlpool, Power Glen, Manitoulin, Cabot Head, and Grimsby formations.

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The Middle Silurian Clinton and Albemarle groups are each composed of two distinct facies. In the Niagara Peninsula, six formations—Thorold, Neagha, Reynales, Irondequoit, Rochester, and DeCew—are recognized in the Clinton, and two formations—Lockport (including the Gasport, Goat Island, and Eramosa members) and Guelph—in the Albemarle group. Throughout the remainder of the escarpment four formations—Dyer Bay, Wingfield, St. Edmund, and Fossil Hill—are assigned to the Clinton, and two formations—Amabel (including four members—Lions Head, Colpoy Bay, Wiarton, and Eramosa) and Guelph—to the Albemarle. Equivalents of both the Eramosa and Guelph are recognizable along the southeast shore of Manitoulin Island. The Wiarton either passes directly upward into Guelph or is overlain by variable thicknesses of Eramosa dolomite. The presence of the latter depends upon biohermal development in the Wiarton. The *Pentamerus*- and coral-rich Fossil Hill dolomite is correlated on stratigraphic evidence with the Lower Clinton *Pentamerus*-bearing Reynales dolomite and is equivalent to the Manistique of northern Michigan. A mixed Racine and Guelph fauna, including a great variety of Crinoidea, Brachiopoda, Pelecypoda, Gastropoda, and Cephalopoda, is located in Bruce Peninsula exposures of the Wiarton member; the Amabel is correlated with the northern Michigan Engadine formation.

CONTRIBUTIONS TO THE AGE OF THE GASPÉ SANDSTONE*

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Restudy of fossils from the lower part of Gaspé sandstone indicates an early Devonian age. The Lower Devonian aspect of the brachiopods is shown by the occurrence of *Rhenorensselaeria*. This genus has previously been recorded from the Ardennes-Eifel region, where it is indicative of the Siegenian and lowest Emsian. The newly discovered occurrence in the Gaspé sandstone of the brachiopod genera *Prionothyris* and *Globithyris* (known elsewhere only from the upper part of the Lower Devonian) further emphasizes the Lower Devonian character of the fauna. "*Spirifer*" *mucronatus* var. *posterus*, previously recorded from the Four Mile Brook beds of western Gaspé, is redetermined as "*Spirifer*" aff. "*S.*" *nictauensis*, a species present in the Lower Devonian of Nova Scotia and probably also in the upper part of the Moose River sandstone of Maine.

The gastropod "*Tropidocyclus*" *rotalinea*, a Hamilton species previously reported from the Gaspé sandstone, is similar to specimens from the upper part of the Moose River sandstone and the upper part of the Lower Devonian beds near Highland Mills, New York.

The occurrence of *Monograptus* sp., cf. *M. vomerinus* and *Monograptus* sp., cf. *M. gothlandicus* in member 3 of the underlying Gaspé limestone suggests that the base of the Devonian system in eastern Gaspé should be placed higher in the Gaspé succession than has been recent practice.

AGE OF THE BERNARDSTON FORMATION

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Reconsideration of the age of the Bernardston formation shows that the brachiopod (*Fimbrispirifer*) upon which the most recent dating was based was inadvertently ascribed to the wrong formation. Examination of thin and polished sections cut from this fossil (preserved in magnetite), fossiliferous magnetite from the Lower Devonian of Nova Scotia, and magnetite from Bernardston, Massachusetts, indicate that the fossil comes from Nova Scotia and not from Bernardston. Spectrograms of magnetite from this brachiopod, from Nova Scotia, and from Bernardston indicate that

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the Bernardston material differs significantly from the brachiopod and the Nova Scotia magnetite in trace-element content.

Spiriferoids similar to or identical with the brachiopod are known from the Lower Devonian iron ores of southwestern Nova Scotia but have not been found at Bernardston. Poorly preserved brachiopods from quartzite at Bernardston do, however, indicate that the Bernardston formation is post-Ordovician—probably pre-Middle Devonian and possibly Silurian in age.

Lateral tracing indicates that the Bernardston formation is probably equivalent to the Clough conglomerate of New Hampshire. It is possible, further, that the Clough conglomerate is equivalent to basal Silurian units of New Jersey, Vermont (Shaw Mountain formation), and the eastern townships of Quebec.

Units overlying the Shaw Mountain formation are probably Silurian and Early Devonian. Tetracorals previously described from one of these units are not suitable for positive generic identification, but are indicative only of a post-Early Ordovician age.

GEOCHEMISTRY AND ORIGIN OF THE GOLD-BEARING QUARTZ VEINS AND LENSES OF THE YELLOWKNIFE GREENSTONE BELT, NORTHWEST TERRITORIES, CANADA

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The economic gold quartz veins and lenses occur within shear zones in steeply dipping greenstones (amphibolites) of Precambrian age. The shear zones consist of chlorite schist which has been highly altered in the vicinity of the quartz veins and lenses. The zones of alteration enveloping the quartz bodies include an adjacent carbonate-sericite zone and an outer chlorite-carbonate zone which grades into the chlorite schist of the shear zone. Throughout the shear zones extensive chlorite-carbonate areas are present which show no intimate spacial relationship to the quartz bodies.

Chemical analyses of samples taken across the strike and down the dip of the shear zones show that there is a marked loss of SiO_2 in the chlorite schist of the shear zones when compared with the amphibolite of the wall rocks. This loss increases in the chlorite-carbonate zones and reaches a maximum in the carbonate-sericite zones. In one shear zone where the quartz lenses occur above extensive carbonate-chlorite schist portions a marked decrease in SiO_2 with depth is evident.

Graphs of the chemical analyses across the width of the alteration zones indicate that the loss of SiO_2 is compensated for by the addition of CO_2 and H_2O. The shape of the SiO_2 concentration line, exhibiting a low adjacent to quartz bodies and increasing in value toward the wall rock, indicates that the SiO_2 has migrated toward the present site of the quartz bodies.

The chemical evidence strongly suggests that CO_2 and H_2O from mineralizing solutions displaced SiO_2 from the alteration zones and chlorite-carbonate areas of the shear zones, and that this SiO_2 migrated toward dilation areas within the shear zones where it was deposited as quartz veins and lenses.

SIGNIFICANCE OF SOME TRACE ELEMENTS IN THE ANIMIKEE IRON FORMATION AND ASSOCIATED ARGILLITES

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Quantitative spectrochemical analyses of Animikee iron formations (from Port Arthur and the Mesabi Range) and of the argillaceous rocks associated with them are compared with similar analyses of marine and fresh-water sediments. The elements investigated include chromium, vanadium, cobalt, nickel, boron, and rubidium. The distribution of values for chromium, vanadium, and boron is very similar to that for marine sediments. The rubidium values obtained are intermediate between

those of marine and fresh-water sediments. No correlation was possible with either marine or fresh-water sediments in the case of cobalt and nickel values.

The results appear to justify the conclusion that the iron formations and associated sediments were deposited in marine waters not very different in composition from those of later geologic periods.

STRATIGRAPHIC VALUE OF DISCOASTERS AND SOME OTHER MICROFOSSILS RELATED TO THE COCCOLITHOPHORES

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Much scientific work has been done on Recent Coccolithophoridae, and some fossil forms have been described, but little attention has been given to their value in biostratigraphy. Some extinct forms which may be closely related to these minute algae have been known under the generic term *Discoaster*. The systematic position of the discoasters is uncertain, and originally Ehrenberg regarded them as inorganic "Crystalldrusen", but it is now evident that they are the skeletal remains of nannoplanktonic organisms. Despite the little taxonomic work done and the difficulties involved, present data indicate the probability that forms of *Discoaster*, especially, may aid in world-wide correlation of certain Tertiary time horizons.

The very small (about 10 microns) calcareous remains of these organisms are common in some late Mesozoic and Tertiary rocks, particularly in those of open-sea deposition, and constitute the main bulk of some chalky sediments. Distinctive forms of *Discoaster* characteristic of certain parts of the Tertiary are found on both sides of the Pacific and Atlantic oceans, including the Caribbean and Mediterranean regions, and elsewhere. Some of these are illustrated and some data presented on their stratigraphic distribution in the middle and early Tertiary.

LOWER DESMOINESIAN STRATIGRAPHY OF NORTHEASTERN OKLAHOMA

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Northeastern Oklahoma was a platform margin bordering the geosynclinal McAlester Basin during Lower Desmoinesian time. Sedimentation was cyclical at most times, but the basin margin extended to the northern line of Oklahoma during some intervals. The stratigraphic units of the area are described, and correlations are discussed.

The entire area has been mapped on a scale greater than 3 inches to the mile, as part of a project of the Oklahoma Geological Survey. The geologic map will be published on a scale of 1 inch to the mile. Formational divisions used are those of the McAlester Basin, but the cyclical units are also discriminated.

MAFIC INTRUSIONS AS A CLUE TO THE METAMORPHIC HISTORY OF THE SPRUCE PINE DISTRICT, NORTH CAROLINA

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The geologic history of the Spruce Pine district of North Carolina can be traced from the sediments that formed the Precambrian rocks through two periods of regional metamorphism to the intrusion of basaltic dikes of Triassic (?) age. The sedimentary rocks were recrystallized and plastically deformed during a Late Ordovician or early Silurian metamorphic cycle. Ultramafic bodies were intruded early; alaskite and associated pegmatites were emplaced late. Uranium-lead measure-

ments indicate that pegmatites formed 350 ± 20 million years ago. An interval of crustal tension, with brecciation of the rocks, culminated in a Devonian (?) invasion by the gabbro stock and dike swarm now cropping out near Bakersville. In a second period of regional metamorphism (Appalachian ?), both gabbro and cementing material of the breccia were recrystallized. Minerals of the altered gabbro include garnet, hornblende, intermediate plagioclase, and cloudy pyroxene. The older, already recrystallized rocks were essentially unaffected by this period of metamorphism, although chlorite formed in shear zones. Intense plastic deformation was absent in the second cycle. Tension cracks following this cycle were filled by diabasic dikes during the Triassic (?) period.

The first metamorphic cycle was probably characterized by moderate to high temperatures, high water concentration, and relatively high rates of metamorphic reaction, effecting plastic behavior of the rocks. During the second cycle, temperatures were probably the same or slightly higher; but lower water concentration retarded metamorphic reaction, effecting brittle behavior of the rocks. Because of differences in water concentration, evidence of two periods of high-temperature metamorphism is not only preserved, but distinguishable.

GEOCHEMICAL ASPECTS OF INTERSTITIAL MATERIAL IN IGNEOUS ROCKS

Harrison Brown, Wilbur J. Blake, Arthur A. Chodos, Richard Kowalkowski, Charles R. McKinney, George J. Neuerburg*, Leon T. Silver, and Aiji Uchiyama
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The chemical composition and lability of "interstitial" material in four rocks have been studied. The Bonsall tonalite from the Southern California batholith yields upon leaching with dilute acid 0.55% leachable material; a granite from Elberton, Georgia, yields 0.39%; a granite from Essonville, Ontario, yields 0.13%; an aplite from the Boulder batholith, Montana, yields 0.091%. The compositions of the material leached from the four rocks with respect to major constituents are remarkably similar. Silica in all cases is low, ranging from 2% to 6%. Major constituents are CaO (15% to 45%), Fe_2O_3(11% to 46%), and Al_2O_3(20% to 32%). The levels of minor constituents in interstitial material vary widely and are related to the trace-element levels in the original rocks and to the chemical natures of the elements.

The rate of removal of interstitial material is dependent upon the hydrogen ion concentration. In 1M acid the interstitial material of the Bonsall tonalite is taken into solution at a rate of 16 per cent per minute; in 0.1M acid the rate of removal is 4.3 per cent per minute at room temperature. Acid is consumed in the solution process, and preliminary experiments indicate that the hydrogen ion consumption amounts to 0.01 mole per gram of interstitial material removed.

Experiments have been run for the purpose of determining the effects of particle size distribution upon the liberation of interstitial material.

LEACHING STUDIES OF INTERSTITIAL MATERIAL IN IGNEOUS ROCKS

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Chemical studies of a group of plutonic igneous rocks indicate that significant proportions of many of the minor elements may be readily removed by leaching in the pulverized state with cold, dilute acid under controlled conditions. Comagmatic rocks (Southern California batholith) and rocks of widely diverse geographic location and geologic history yield soluble material of rather uniform gross composition. Minor elements extracted show considerable variation, but many are considerably concentrated with respect to the gross rock. Up to 40 per cent of the radioactive elements and rare

* *U. S. Geological Survey, Pasadena, Calif.*

earths in a granite may be found in leachable material, representing considerably less than 1 per cent of the total weight of the rock. Greatest trace-element enrichment occurs where ionic radius and charge hinder admission of the element to the major mineral phases.

Several sources may contribute to the acid leaches. These include, in addition to solution of major minerals, minor amounts of alteration minerals such as calcite and zeolites; certain accessory minerals, particularly if metamict; and, apparently, submicroscopic material dispersed along fractures and grain boundaries. Mechanical fractionation according to particle size and mineral composition aids the recognition of the individual contributions from the various sources. Special efforts to control external contamination have been made.

The dispersed submicroscopic material, here called "interstitial", plays an important, generally unrecognized, role in the trace-element character of igneous rocks. It particularly affects trace-element determinations and age measurements on rocks and rock minerals and may yield important information on many rock-forming and rock-modifying processes.

LATE FAULTS IN THE YELLOWKNIFE AREA, CANADA

Ira C. Brown
Geological Survey, Dept. of Mines and Technical Surveys, Ottawa, Canada

A major late Precambrian fault system extends from Yellowknife Bay, on the north shore of Great Slave Lake, to Indin Lake 130 miles to the northwest. It branches at each end in Archean volcanic and sedimentary rocks and is a single fault in the granitic rocks between. The southern part of the system, within the Yellowknife greenstone belt, has been mapped on a scale of 500 feet to 1 inch.

The faults are sharp-walled breccia zones seldom more than 4 feet wide and commonly only a few inches in width. Movement varies from inches on minor faults to miles on major ones, but all are narrow fractures. Faults are commonly sinuous, but some curve sharply in short distances. The amount of movement may change greatly along a single fault.

A sharp bulge in the West Bay fault has resulted in considerable deformation of the lavas east of it and development of the complementary Akaitcho fault. A similar bulge in the Kam fault has developed the complementary Pud fault, and, in the block of ground between them, three sets of faults that illustrate the two shear directions theoretically required by the strain ellipsoid.

From the relations of the major faults to the complementary faults and other minor structures it is deduced that the fault system was formed by shear forces which moved the active west side south relative to the static east side.

EXPLOSION PIPE IN TEST WELL ON HICKS DOME, HARDIN COUNTY, ILLINOIS

John S. Brown, J. A. Emery, and P. A. Mayer, Jr.
c/o St. Joseph Lead Co., Geological Dept., Bonne Terre, Mo.

In 1952, St. Joseph Lead Company drilled a well on the apex of Hick's dome in Hardin County, Illinois, primarily to explore for oil or gas, and with the objective of testing the St. Peter sand horizon, which had not been reached in a previous well on the flank of the dome. A normal sequence of formations was encountered down to 1600 feet, but at about that depth the drill entered a confused brecciated zone, which persisted to the bottom of the hole at 2944 feet. This is interpreted as one of the explosion-type breccias, or diatremes, common in this Illinois-Kentucky area, as well as in near-by Missouri.

Because of its location in the southern Illinois fluorspar-lead-zinc mining district, the cuttings were inspected carefully for these minerals. The brecciated portion of the hole was mineralized continuously but erratically with fluorspar generally ranging from about 5 per cent in the upper portion of the breccia to 2 per cent at the bottom.

STRUCTURAL AND DECREPITATION FEATURES OF THE GOLD MINERALIZATION AT THE O'BRIEN MINE, QUEBEC*

Roger A. Blais
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Quartz veins of distinctive structural pattern and characteristic wall-rock alteration form the environment of gold deposition at the O'Brien mine. Fracturing and shattering of vein quartz afforded minute openings for migration of auriferous solutions, and the late gold was concentrated in, or near, structures favoring such brecciation of vein quartz. The ore shoots have almost vertical pitch, with a great pitch length in comparison to stope length.

The observed relationships of minor-scale fracturing of vein quartz to gold deposition and to planes of secondary liquid inclusions form the basis for this extensive study of vein quartz. The decrepitometric data for 1000 quartz samples indicates relationships between liquid inclusion decrepitation and distribution of ore values. Auriferous vein quartz is characterized by decrepitation temperatures from 75°C to 120°C, whereas barren quartz starts to decrepitate above 130°C. Trend lines of low decrepitation temperatures correspond to ore chimneys. It is suggested that barren sections of quartz veins have not been reworked during the gold stage and, consequently, do not show low-temperature decrepitation, which appears to be due to characteristic liquid inclusions trapped in intra-mineralization fractures of vein quartz.

ISOTOPIC ABUNDANCES IN ROCKS AND METEORITES

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Hydrogen, nitrogen, and carbon isotopes were studied in a number of rocks and meteorites to clarify some aspects of the problem of the loss of volatiles from the planetary system and of the origin and formation of the atmosphere.

Hydrogen isotopes were analyzed in the water contained in stony meteorites and igneous rocks: the abundance of deuterium in these samples is explainable with single-stage fractionation processes. No nuclear or multiple fractionation processes seem to be involved, and therfore one can conclude that the abundance of hydrogen isotopes does not change remarkably through the planetary system, except for the sun where the deuterium was consumed by nuclear reactions. Particularly interesting are the carbonaceous chondrites, which contain up to 10 per cent of water and show a minimum of contamination by terrestrial water. The percentage difference in the D/H ratio in these meteorites ranges from -5 per cent to $+20$ per cent as referred to the average ocean water. Carbon isotopes were also analyzed in these meteorites; they show a high C^{13} content with respect to the average on the earth and to the ordinary chondrites. Nitrogen isotope ratios have been measured in rocks. Amounts of nitrogen of 0.1 cc are easily extracted and analyzed with the developed technique. N^{15}/N^{14} variations of some per cent with respect to the atmospheric nitrogen were found.

SILURIAN STRATA OF THE NIAGARA ESCARPMENT, ONTARIO†

T. E. Bolton
Geological Survey of Canada, Ottawa

Strata exposed in the Ontario portion of the Niagara escarpment are assigned to three groups. The Lower Silurian Cataract group, representing a complete sedimentary cycle from transgression to regression, consists of the Whirlpool, Power Glen, Manitoulin, Cabot Head, and Grimsby formations.

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The Middle Silurian Clinton and Albemarle groups are each composed of two distinct facies. In the Niagara Peninsula, six formations—Thorold, Neagha, Reynales, Irondequoit, Rochester, and DeCew—are recognized in the Clinton, and two formations—Lockport (including the Gasport, Goat Island, and Eramosa members) and Guelph—in the Albemarle group. Throughout the remainder of the escarpment four formations—Dyer Bay, Wingfield, St. Edmund, and Fossil Hill—are assigned to the Clinton, and two formations—Amabel (including four members—Lions Head, Colpoy Bay, Wiarton, and Eramosa) and Guelph—to the Albemarle. Equivalents of both the Eramosa and Guelph are recognizable along the southeast shore of Manitoulin Island. The Wiarton either passes directly upward into Guelph or is overlain by variable thicknesses of Eramosa dolomite. The presence of the latter depends upon biohermal development in the Wiarton. The *Pentamerus*- and coral-rich Fossil Hill dolomite is correlated on stratigraphic evidence with the Lower Clinton *Pentamerus*-bearing Reynales dolomite and is equivalent to the Manistique of northern Michigan. A mixed Racine and Guelph fauna, including a great variety of Crinoidea, Brachiopoda, Pelecypoda, Gastropoda, and Cephalopoda, is located in Bruce Peninsula exposures of the Wiarton member; the Amabel is correlated with the northern Michigan Engadine formation.

CONTRIBUTIONS TO THE AGE OF THE GASPÉ SANDSTONE*

A. J. Boucot and L. M. Cumming
U. S. Geological Survey, Washington, D.C.; Geological Survey of Canada, Ottawa, Canada

Restudy of fossils from the lower part of Gaspé sandstone indicates an early Devonian age. The Lower Devonian aspect of the brachiopods is shown by the occurrence of *Rhenorensselaeria*. This genus has previously been recorded from the Ardennes-Eifel region, where it is indicative of the Siegenian and lowest Emsian. The newly discovered occurrence in the Gaspé sandstone of the brachiopod genera *Prionothyris* and *Globithyris* (known elsewhere only from the upper part of the Lower Devonian) further emphasizes the Lower Devonian character of the fauna. "*Spirifer*" *mucronatus* var. *posterus*, previously recorded from the Four Mile Brook beds of western Gaspé, is redetermined as "*Spirifer*" aff. "*S.*" *nictauensis*, a species present in the Lower Devonian of Nova Scotia and probably also in the upper part of the Moose River sandstone of Maine.

The gastropod "*Tropidocyclus*" *rotalinea*, a Hamilton species previously reported from the Gaspé sandstone, is similar to specimens from the upper part of the Moose River sandstone and the upper part of the Lower Devonian beds near Highland Mills, New York.

The occurrence of *Monograptus* sp., cf. *M. vomerinus* and *Monograptus* sp., cf. *M. gothlandicus* in member 3 of the underlying Gaspé limestone suggests that the base of the Devonian system in eastern Gaspé should be placed higher in the Gaspé succession than has been recent practice.

AGE OF THE BERNARDSTON FORMATION

Arthur J. Boucot, Richard S. Harner, Gordon MacDonald, and Charles Milton
U. S. Geological Survey, Washington, D.C.; U. S. Geological Survey, Washington, D. C.; Harvard University, Cambridge, Mass.; U. S. Geological Survey, Washington, D.C.

Reconsideration of the age of the Bernardston formation shows that the brachiopod (*Fimbrispirifer*) upon which the most recent dating was based was inadvertently ascribed to the wrong formation. Examination of thin and polished sections cut from this fossil (preserved in magnetite), fossiliferous magnetite from the Lower Devonian of Nova Scotia, and magnetite from Bernardston, Massachusetts, indicate that the fossil comes from Nova Scotia and not from Bernardston. Spectrograms of magnetite from this brachiopod, from Nova Scotia, and from Bernardston indicate that

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the Bernardston material differs significantly from the brachiopod and the Nova Scotia magnetite in trace-element content.

Spiriferoids similar to or identical with the brachiopod are known from the Lower Devonian iron ores of southwestern Nova Scotia but have not been found at Bernardston. Poorly preserved brachiopods from quartzite at Bernardston do, however, indicate that the Bernardston formation is post-Ordovician—probably pre-Middle Devonian and possibly Silurian in age.

Lateral tracing indicates that the Bernardston formation is probably equivalent to the Clough conglomerate of New Hampshire. It is possible, further, that the Clough conglomerate is equivalent to basal Silurian units of New Jersey, Vermont (Shaw Mountain formation), and the eastern townships of Quebec.

Units overlying the Shaw Mountain formation are probably Silurian and Early Devonian. Tetracorals previously described from one of these units are not suitable for positive generic identification, but are indicative only of a post-Early Ordovician age.

GEOCHEMISTRY AND ORIGIN OF THE GOLD-BEARING QUARTZ VEINS AND LENSES OF THE YELLOWKNIFE GREENSTONE BELT, NORTHWEST TERRITORIES, CANADA

R. W. Boyle
Geological Survey of Canada, Ottawa, Canada

The economic gold quartz veins and lenses occur within shear zones in steeply dipping greenstones (amphibolites) of Precambrian age. The shear zones consist of chlorite schist which has been highly altered in the vicinity of the quartz veins and lenses. The zones of alteration enveloping the quartz bodies include an adjacent carbonate-sericite zone and an outer chlorite-carbonate zone which grades into the chlorite schist of the shear zone. Throughout the shear zones extensive chlorite-carbonate areas are present which show no intimate spacial relationship to the quartz bodies.

Chemical analyses of samples taken across the strike and down the dip of the shear zones show that there is a marked loss of SiO_2 in the chlorite schist of the shear zones when compared with the amphibolite of the wall rocks. This loss increases in the chlorite-carbonate zones and reaches a maximum in the carbonate-sericite zones. In one shear zone where the quartz lenses occur above extensive carbonate-chlorite schist portions a marked decrease in SiO_2 with depth is evident.

Graphs of the chemical analyses across the width of the alteration zones indicate that the loss of SiO_2 is compensated for by the addition of CO_2 and H_2O. The shape of the SiO_2 concentration line, exhibiting a low adjacent to quartz bodies and increasing in value toward the wall rock, indicates that the SiO_2 has migrated toward the present site of the quartz bodies.

The chemical evidence strongly suggests that CO_2 and H_2O from mineralizing solutions displaced SiO_2 from the alteration zones and chlorite-carbonate areas of the shear zones, and that this SiO_2 migrated toward dilation areas within the shear zones where it was deposited as quartz veins and lenses.

SIGNIFICANCE OF SOME TRACE ELEMENTS IN THE ANIMIKEE IRON FORMATION AND ASSOCIATED ARGILLITES

B. A. Bradshaw
Department of Geological Sciences, University of Toronto, Toronto, Canada

Quantitative spectrochemical analyses of Animikee iron formations (from Port Arthur and the Mesabi Range) and of the argillaceous rocks associated with them are compared with similar analyses of marine and fresh-water sediments. The elements investigated include chromium, vanadium, cobalt, nickel, boron, and rubidium. The distribution of values for chromium, vanadium, and boron is very similar to that for marine sediments. The rubidium values obtained are intermediate between

those of marine and fresh-water sediments. No correlation was possible with either marine or fresh-water sediments in the case of cobalt and nickel values.

The results appear to justify the conclusion that the iron formations and associated sediments were deposited in marine waters not very different in composition from those of later geologic periods.

STRATIGRAPHIC VALUE OF DISCOASTERS AND SOME OTHER MICROFOSSILS RELATED TO THE COCCOLITHOPHORES

M. N. Bramlette and W. R. Riedel
Scripps Institution of Oceanography, La Jolla, Calif.

Much scientific work has been done on Recent Coccolithophoridae, and some fossil forms have been described, but little attention has been given to their value in biostratigraphy. Some extinct forms which may be closely related to these minute algae have been known under the generic term *Discoaster*. The systematic position of the discoasters is uncertain, and originally Ehrenberg regarded them as inorganic "Crystalldrusen", but it is now evident that they are the skeletal remains of nannoplanktonic organisms. Despite the little taxonomic work done and the difficulties involved, present data indicate the probability that forms of *Discoaster*, especially, may aid in world-wide correlation of certain Tertiary time horizons.

The very small (about 10 microns) calcareous remains of these organisms are common in some late Mesozoic and Tertiary rocks, particularly in those of open-sea deposition, and constitute the main bulk of some chalky sediments. Distinctive forms of *Discoaster* characteristic of certain parts of the Tertiary are found on both sides of the Pacific and Atlantic oceans, including the Caribbean and Mediterranean regions, and elsewhere. Some of these are illustrated and some data presented on their stratigraphic distribution in the middle and early Tertiary.

LOWER DESMOINESIAN STRATIGRAPHY OF NORTHEASTERN OKLAHOMA

Carl C. Branson
School of Geology, University of Oklahoma, Norman, Okla.

Northeastern Oklahoma was a platform margin bordering the geosynclinal McAlester Basin during Lower Desmoinesian time. Sedimentation was cyclical at most times, but the basin margin extended to the northern line of Oklahoma during some intervals. The stratigraphic units of the area are described, and correlations are discussed.

The entire area has been mapped on a scale greater than 3 inches to the mile, as part of a project of the Oklahoma Geological Survey. The geologic map will be published on a scale of 1 inch to the mile. Formational divisions used are those of the McAlester Basin, but the cyclical units are also discriminated.

MAFIC INTRUSIONS AS A CLUE TO THE METAMORPHIC HISTORY OF THE SPRUCE PINE DISTRICT, NORTH CAROLINA

Donald A. Brobst, Arie Poldervaart, and J. Laurence Kulp
U. S. Geological Survey, Washington 25, D. C.; Dept. of Geology, Columbia University, New York, N. Y.; U. S. Geological Survey, Dept. of Geology, Columbia University, New York, N. Y.

The geologic history of the Spruce Pine district of North Carolina can be traced from the sediments that formed the Precambrian rocks through two periods of regional metamorphism to the intrusion of basaltic dikes of Triassic (?) age. The sedimentary rocks were recrystallized and plastically deformed during a Late Ordovician or early Silurian metamorphic cycle. Ultramafic bodies were intruded early; alaskite and associated pegmatites were emplaced late. Uranium-lead measure-

ments indicate that pegmatites formed 350 ± 20 million years ago. An interval of crustal tension, with brecciation of the rocks, culminated in a Devonian (?) invasion by the gabbro stock and dike swarm now cropping out near Bakersville. In a second period of regional metamorphism (Appalachian ?), both gabbro and cementing material of the breccia were recrystallized. Minerals of the altered gabbro include garnet, hornblende, intermediate plagioclase, and cloudy pyroxene. The older, already recrystallized rocks were essentially unaffected by this period of metamorphism, although chlorite formed in shear zones. Intense plastic deformation was absent in the second cycle. Tension cracks following this cycle were filled by diabasic dikes during the Triassic (?) period.

The first metamorphic cycle was probably characterized by moderate to high temperatures, high water concentration, and relatively high rates of metamorphic reaction, effecting plastic behavior of the rocks. During the second cycle, temperatures were probably the same or slightly higher; but lower water concentration retarded metamorphic reaction, effecting brittle behavior of the rocks. Because of differences in water concentration, evidence of two periods of high-temperature metamorphism is not only preserved, but distinguishable.

GEOCHEMICAL ASPECTS OF INTERSTITIAL MATERIAL IN IGNEOUS ROCKS

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Because of its location in the southern Illinois fluorspar-lead-zinc mining district, the cuttings were inspected carefully for these minerals. The brecciated portion of the hole was mineralized continuously but erratically with fluorspar generally ranging from about 5 per cent in the upper portion of the breccia to 2 per cent at the bottom.

This is much deeper than previously known in such amounts in the area. Parallel with the fluorspar content and similarly diminishing downward is an abnormal radioactivity characterized by .029 per cent U_3O_8 in the upper part of the breccia zone. The possibility is suggested that this could have been picked up from the formerly overlying New Albany, or Chattanooga, shale.

FRACTURE PATTERN AND URANIUM ORE OF THE ZUNI UPLIFT, NEW MEXICO

Walter H. Bucher and Arthur K. Gilkey*
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In 1951, under the Atomic Energy Commission's auspices and under the direction and for a time in company with Walter H. Bucher, Arthur Gilkey studied the joints and faults of the Zuni Uplift as part of a comparative study of the fracture patterns of domed areas. Gilkey also studied two elongated narrow folds formed by horizontal movement (Virginia Appalachians and Marathon basin) and one domed by intrusion from below (Maze Arch, Henry Mountains). His observations bore out conclusions derived from the literature, that in laterally compressed folds the chief faults and dominant joints cut the axis at high angles (70°–90°). In updomed areas, they parallel the axis.

The relatively flat top; the shape due to more or less well-defined flexures; and faults and flexures that cut the uplift suggest that the Zuni Uplift is the result of differential upward movement along faults cutting the crystalline basement.

The angular relations that exist among the faults and flexures are those obtained on the surface of a cube of clay deformed by gentle compression. The upward movement that changes the fractures into "faults" is inherent in the process.

In each structural unit of the uplift, the dominant joints in the sediments tend to parallel the nearest controlling fault or flexure, as if the differential movement had stretched the sedimentary cover. Since this movement originates at depth, the fault displacement must have started there and advanced toward the surface, localizing the stresses in the sediments above.

The association of the uranium ore with fluorite replacing the Todilto limestone in the Grants region and the elongation of the ore-rich areas, delineated by drilling, parallel to the local fracture pattern, suggest a causal connection between ore and fractures.

TRIMORPHISM IN ZINC SULFIDE

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Sylvania Electric Products Inc., Bayside, Long Island, N. Y.

Experimental evidence was found for the existence of a third polymorphic modification of zinc sulfide. In addition to β zinc sulfide (zincblende or sphalerite) and α zinc sulfide (wurtzite) structures, a three-layer rhombohedral structure was found in the temperature range of approximately 850° C to 1020° C. This structure is similar to the zincblende structure referred to hexagonal axes wherein the c and a interatomic distances are slightly altered. In conformity with conventional nomenclature it is designated γ-zinc sulfide.

The experimental evidence for the existence of rhomdohedral zinc sulfide is the fine structure of cubic (111) x-ray reflections as observed with high-resolution spectrometer studies on pure zinc sulfide heated to various temperatures and quenched.

The relation of the rhombohedral structure to the following phenomena have been studied: (1) the temperature-dependence of interplaner spacings of (111) cubic and (100) hexagonal, (2) stacking

* Arthur Gilkey was swept to his death by an avalanche on Mt. Godwin Austen in the Karakoram Range, in Kashmir, as a member of an American climbing expedition—*W. H. Bucher*

faults in the rhombohedral lattice, and (3) the existence, relative concentrations, and size of multi-layered polytypes in the temperature range 800° C–1020° C.

IRON AND TITANIUM OXIDE MINERALS OF ADIRONDACK ROCKS

A. F. Buddington, Joseph Fahey and Angelina Vlisidis
U. S. Geological Survey, Princeton, N. J.; U. S. Geological Survey, Washington, D. C.; U. S. Geological Survey, Washington, D. C.

In igneous rocks of the Adirondack region the amount of TiO_2 in ilmenomagnetite (magnetite with exsolved ilmenite) is greatest in some ore segregations in gabbro and anorthosite (12 to 14 per cent), less in hornblende microperthite granite (5 to 6.7 per cent), and least in microperthite alaskite (3.0 to 4.3 per cent). The titanium variation in the ilmenomagnetite of these plutonic rocks parallels that found by Japanese geologists in magnetite of basaltic, andesitic, and rhyolitic volcanic rocks in Japan; it is a function of temperature of formation and affords a wide-range temperature scale. The composition of the ilmenomagnetite, both that accessory in granite and that in ore concentrations in gabbro and anorthosite, leads to an inference of formation at *magmatic* temperatures.

The magnetite of microcline-rich *granitized* rocks, formed at temperatures lower than magmatic, has about 2.2 to 3.1 per cent TiO_2. The TiO_2 in magnetite of gnesisses reconstituted in the upper temperature range of granulite-amphibolite facies is 3.1 to 4.1 per cent; in the lower range of amphibolite facies it is only 1 to 2 per cent. Free ilmenite is present in all samples.

Six different oxide assemblages that were analyzed have the *same* ratio of iron to titanium but differ largely in degree of oxidation. The least-oxidized combination (magnetite, ilmenite, and (?) ferrous orthotitanate) occurs in olivine gabbro, and the most-oxidized facies (rutilohematite and rutile) in a microcline-rich granitic gneiss formed from metasediments by potash-rich fluids. The Fe_2O_3 in solid solution in magnetite in granite and gneiss decreases with temperature of formation.

CRYSTAL STRUCTURE OF BERTHIERITE, $FeSb_2S_4$

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The unit cell, space group, and approximate structure of berthierite were reported in earlier communications. The rough structure has now been refined. The observed amplitudes $|F_{hk0}|$ were first put on an absolute basis by Wilson's method which also determined the temperature coefficient, $B = 1.05$. The refinement was carried out by using successive Fourier syntheses, $(F_o\text{-}F_o)$ syntheses, and by fitting the Patterson of the proposed structure to the details of the observed Patterson. The final structure has the following parameters: Fe[.314, .335, $\frac{1}{4}$]; Sb_1[.145, .064, $\frac{1}{4}$]; Sb_2[.036, .385, $-\frac{1}{4}$]; S_1[.197, .272, $-\frac{1}{4}$]; S_2[.428, .186, $\frac{1}{4}$]; S_3[.229, .494, $\frac{1}{4}$]; and S_4[.452, .405, $\frac{1}{4}$]. The new parameters are within a few thousandths of the values determined directly by minimum-function methods. Using these final parameters, a refined absolute F_{obs} scale and temperature coefficient were computed. The residual error, $R = (\sum \| F_o \| - | F_c \|) / \sum | F_o |$, is .142 for *hk*0 and .126 for *h*0*l*.

Each antimony atom is bonded to three sulfur atoms at distances of about 2.5Å, and these SbS_3 groups share sulfur atoms to form chains running parallel to the *c* axis. The iron atoms are surrounded by six sulfur atoms in approximately octohedral arrangement. These octohedra share edges to form chains parallel to the *c* axis. The Fe-S distance, however, is about 2.5Å, which is considerably in excess of that found in structures where the bonds are recognized as covalent (pyrite, 2.26Å, marcasite, 2.24Å). The distance is about what would be expected for ionic Fe-S bonds. The structure can therefore probably be regarded as $Fe^{++}(SbS_2)_2^-$.

CRYSTAL STRUCTURE OF LIVINGSTONITE, $HgSb_4S_7$

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The unit cell and space group of livingstonite were investigated by Gorman. His triclinic cell has the following dimensions: $a = 7.650$ Å, $b = 10.817$, $c = 3.990$; $\alpha = 99°12\frac{1}{2}'$, $\beta = 102°01'$, $\gamma = 73°48'$. This cell contains 1 $HgSb_4S_7$. Because of the shortness of the c axis, we thought it might be relatively easy to determine the structure as projected parallel to c. $F^2(hk0)$ intensity data were obtained from a c axis Weissenberg photograph processed by the M.I.T. modification of the Dawton method. With these data a Patterson map was prepared. The one Hg atom can be taken as located at the origin of Gorman's cell. A quantitative interpretation of the peak heights of the Patterson map located the Sb atoms. An M_8 minimum-function map confirmed these locations and delimited areas available for sulfur atoms.

The structure was approached by successive Fourier syntheses. Phases for the F_{obs} $(hk0)$'s were approximated by assuming that the Hg and Sb's determined the phases provided they accounted for at least a third of the full amplitude. Each successive Fourier synthesis revealed one or more sulfur atoms, which were then taken into account when new phases for a next Fourier synthesis were computed.

One of the seven S atoms should occupy an inversion center provided livingstonite is centrosymmetrical and provided the formula is correct. We found no S atom in such a position, but did find a somewhat weak pair of peaks in a general position.

The xy coordinates found are as follows:

	x	y
Hg	0	0
2 Sb_I	.473	.146
2 Sb_{II}	.164	.428
2 S_I	.243	.180
2 S_{II}	.929	.364
2 S_{III}	.694	.087
2 S_{IV}	.598	.444

This structure investigation is being continued.

STRUCTURE OF AMISK-WILDNEST LAKE AREA, CANADA*

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The Amisk-Wildnest Lake region lies west of the Saskatchewan-Manitoba boundary between latitudes 54° 30′ N. and 55° 00′ N.

The Precambrian stratigraphic sequence comprises three groups: (1) the Amisk, a volcanic-sedimentary assemblage; (2) the Missi, a sedimentary series unconformably overlying the Amisk; (3) the Kisseynew, a group of gneisses which are the metamorphosed equivalent of parts of the Amisk and Missi.

Pre-tectonic, syntectonic, and post-tectonic intrusive sequences are recognized. The most abundant and structurally important are the syntectonic intrusions which have an average composition of granodiorite. They intrude Amisk, Missi, and Kisseynew rocks and form large masses elongated parallel to the regional structures. Some are huge sills and laccoliths, and others are conformable batholiths or large phacoliths.

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* Publication authorized by Director, Saskatchewan Geological Survey

Amisk and Missi strata are isoclinally folded. The axial planes of the major folds have steep to vertical dips, but many of the minor folds are overturned. The plunge is either north to northwest or east to southeast. The folds in the Kisseynew are complex overturned isoclinal folds plunging east and open symmetrical to asymmetrical northerly plunging folds. Cleavage in the Amisk-Missi strata is essentially axial plane, whereas in the Kisseynew gneisses it is a bedding foliation.

There is considered to be no major time interval between Amisk and Missi, the Kisseynew is regarded as their metamorphosed equivalent, and it is postulated that one major period of deformation affected the Amisk, Missi, and Kisseynew strata.

POLARIZATION FIGURES AND ROTATION PROPERTIES—SUMMARY OF PROGRESS

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Polarization figures and rotation properties have been under investigation at the University of Wisconsin since 1950. The studies have dealt with theoretical problems, sources of error in interpretation of polarization figures and in measurement of rotation properties, and measurements of rotation properties of various minerals.

Theoretical studies in general substantiate the explanation of polarization figures given by Cameron and Green in 1950, but certain corrections are necessary.

A number of sources of error in the interpretation of polarization figures and in the measurement of rotation properties are inherent in the optical system of the reflecting microscope. These have been investigated and evaluated. Most can be dealt with by proper adjustment of the microscope. Errors introduced by the reflecting plate are substantial but systematic. For each microscope a curve can be constructed for correction of measured rotation angles. Errors due to strain in objectives are serious, but can be avoided by use of unstrained objectives now obtainable.

Microscopic equipment currently in use for routine examination of minerals in reflected light is not ideal for study of polarization figures. The modifications required, however, are slight.

Studies of the rotation properties of the tellurides, the cobalt-nickel arsenides and associated minerals, a series of sulphosalts of lead, columbium-tantalum minerals, and various other minerals indicate that rotation properties will be a practical aid in the identification of anisotropic minerals. The rotation properties of isotropic minerals are less distinctive, but there is some hope that extension of present methods will facilitate their identification on the basis of optical properties.

LATE PLEISTOCENE EUSTATIC CHANGES IN SEA LEVEL IN CAPE BRETON ISLAND, NOVA SCOTIA

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Evidence of higher sea levels is abundant in the central and western parts of Cape Breton. Marine benches and terraces also occur around the entire coast line and river terraces on some of the larger rivers. Barometer checks, air-photograph checks against contour maps, and parallax heighting have established the elevations of a number of these features, with the most prominent at ±35 feet and ±210 feet. The general agreement in height of these features throughout the island is interpreted as indicating that they were formed by eustatic changes in sea level. Higher and intermediate features can be interpreted as due to local conditions of erosion, or to warped strand lines similar to those found in Newfoundland and on the mainland of Nova Scotia. The dating of these features is tentatively late Pleistocene. More exact dating is expected from carbon 14 measurements on wood samples

from various localities on the island. General evidence of glaciation indicates that the entire island was covered by an early Pleistocene ice sheet, with local glaciation in a later stage.

C^{14} CONCENTRATION IN MODERN CARBON

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The accuracy of the absolute age of a sample dated by the C^{14} method depends on the specific activity of modern carbon.

Measurements have been made on the following contemporary materials: (1) 12 different woods collected on the Lamont grounds; (2) 26 air samples selected to show possible variation with physiography, climate, altitude, humidity, and time of day; (3) 24 shell or associated meat samples; and (4) a number of surface sea-water samples.

Previous results indicated that the specific activity was constant for modern wood. A comparison of these data with those obtained in other laboratories shows that within the present assumed 5 per cent error the C^{14} concentration in wood, air, surface-ocean carbonate, shell, and clam or oyster meat is the same (*i.e.*, about 15 dpm/gm).

If the C^{14} produced in the upper atmosphere is well mixed within a century, variations in the rate of production with latitude will not affect the C^{14} ages. The results reported lend substantial support to this underlying assumption of the method.

TEST WELL AT KOTZEBUE, ALASKA

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In the summers of 1949–1950 a test well was drilled at Kotzebue to a depth of 325 feet by the cable-tool method. Permafrost extended to a depth of 238 feet. Sediments encountered were largely marine clays overlying continental (?) silts. Salt water was encountered in a thawed zone at 80 feet and again below the permafrost mass between 238 and 325 feet. A gas (methane ?) accumulation was present beneath the permafrost.

Difficulties encountered are evaluated, in order of difficulty, as follows: (1) logistical, (2) lack of, or excessively high cost of, local technical services and materials, (3) personnel, (4) permafrost.

Development of a shallow water zone might profitably be investigated. This would involve stripping of the tundra, melting out the upper permafrost zone by natural or artificial means, and protection of the thawed area by thick snow cover in the winter. The efficacy of the scheme in winter would depend largely upon inflow of water from any adjacent unfrozen zones that may be present between the winter frost and the permafrost.

CAULDRON SUBSIDENCE AT MOUNT DESERT ISLAND, MAINE

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Two masses of pink granite underlie about half of Mount Desert Island, Maine. A uniform coarse-grained hornblende granite has intruded, hornfelsed, and granitized siliceous and shaly sedimentary rocks of Silurian (?) age. A shell of intense shattering is conspicuous in the country rock along the entire extent of the intrusive contact. This shell is approximately half a mile wide. It grades inward from undisturbed country rock, through breccia without granitic material, to injected and granitized breccia, to inclusion-rich chill granite, to inclusion-poor chill granite, and finally to normal granite.

A smaller mass of medium-grained biotite granite cuts out the hornblende granite in its northwestern part. The contact between the two is sharp; a slight chill effect is developed in the biotite granite; and biotite granite dikes cut the hornblende granite. No shatter zone appears to have formed, and no inclusions of hornblende granite were observed. Along half its perimeter, the biotite granite contact is formed by an ill-defined shatter zone 2 miles wide. The zone is developed in fine- to coarse-grained gabbro-diorite which is older than either type of granite.

It is concluded that the granite bodies were implaced by cauldron subsidence. Evidence supporting this interpretation includes: (1) smooth, rounded contacts; (2) partially preserved arching roof; (3) small screen between the granites; (4) contact shatter zone; (5) tangential granite satellites; (6) tangential pegmatite veins; and (7) centripetal dips in breccia and bedding of slightly disturbed metasediments.

OUTLET OF LAKE ALGONQUIN AT FOSSMILL, ONTARIO, CANADA

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A new outlet for glacial Lake Algonquin has been found; the channel runs east from Fossmill along the route of the Canadian National Railway and Petawawa River into the Champlain (Ottawa) Sea near Petawawa. The sill is at an elevation of about 1130 feet above sea level. The level of Lake Algonquin dropped at least 160 feet and possibly 340 feet with the opening of this outlet. This would have uncovered the sites of buried shallow-water sands at Roches Point and Alliston, Ontario, and possibly the peat near Sand Island which F. B. Taylor considered of early Nipissing age and which was used by Flint and Deevey as a key sample in radiocarbon dating. Also this drop in water levels must have lowered the lake below the lowest beaches described by Stanley and Deane on the Penetang Peninsula and Cape Rich. This and the lack of a series of outlets appear to discredit Stanley's hypothesis that the lower Algonquin beaches are related to outlets eastward.

CRYSTAL CHEMICAL STUDIES OF BORATE MINERALS

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For the known members of the series $2CaO \cdot 3B_2O_3 \cdot xH_2O$, x = 13, 9, 7, and 5. The $2CaO \cdot 3B_2O_3 \cdot 9H_2O$ is known only as a synthetic mineral. X-ray studies yield the following data:

Mineral Composition System Space group	Inyoite $2CaO \cdot 3B_2O_3 \cdot 13H_2O$ Monoclinic $P2_1/a$ (C_{2h}^5)	Artificial $2CaO \cdot 3B_2O_3 \cdot 9H_2O$ Triclinic P1 (C_1^1)	Meyerhofferite $2CaO \cdot 3B_2O_3 \cdot 7H_2O$ Triclinic P1 (C_1^1)	Colemanite $2CaO \cdot 3B_2O_3 \cdot 5H_2O$ Monoclinic $P2_1/a$ (C_{2H}^5)
Z	2	1	1	2
a_0	10.63Å	7.04$_6$Å	6.61Å	8.743Å
b_0	12.06	9.45$_2$	8.35	11.264
c_0	8.40$_5$	6.41$_2$	6.49	6.102
α	(90°00′)	101°21′	91°00′	(90°00′)
β	114°02′	101°19′	101°31′	110°07′
γ	(90°00′)	99°49′	86°55′	(90°00′)
Volume	984.1Å^3	400.7Å^3	350.5Å^3	564.2Å^3
Vol./0-atom	20.5Å^3	20.0Å^3	19.5Å^3	17.6Å^3

Colemanite seems to contain sheets of oxygen ions linked by boron ions, parallel to the perfect cleavage plane (010). The study of this structure and its relationship to the structures of the other members of the series is being continued.

CRYSTAL STRUCTURE OF MURDOCHITE

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The crystal structure of the new Cu-Pb-O mineral murdochite has been established. It is an ordered NaCl type, approximate formula Cu_4PbO_5, space group Fm3m (O_h^5) with atomic parameters (000; 0 ½ ½; ½ 0 ½; ½ ½ 0) +

4Pb: (a) 000
8 O_I: (c) ¼ ¼ ¼; ¾ ¾ ¾
24 O_{II}: (e) x00; 0x0; 00x; x̄00; 0x̄0; 00x̄ with x ≐ ¼

The 24 Cu atoms of the cell are distributed statistically over the 28 sites given by:

4Cu_{II}: (b) ½ ½ ½
24Cu_I: (d) 0 ¼ ¼; ¼ 0 ¼; ¼ ¼ 0; 0 ¼ ¾; ¾ 0 ¼; ¼ ¾ 0

CONTACT METAMORPHISM IN THE CHRISTMAS MOUNTAINS, BREWSTER COUNTY, TEXAS

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Spurrite, gehlenite, wollastonite, and other high-temperature contact-metamorphic minerals occur in a well-defined skarn zone at the contact between Lower Cretaceous limestone and gabbro in the central part of the Christmas Mountains. Superimposed on the high-temperature mineralization is hydrothermal contact metamorphism associated with small, irregular apophyses of pyroxene syenite and nepheline syenite. Irregular stringers of aplitic nepheline-analcime syenite in fractures in the upper part of the gabbro appear to be local differentiates of the gabbro. Clinozoisite and zeolites are associated with the nepheline syenite, and syenite projections into the skarn are rich in sphene, strongly pleochroic titanaugite, and schorlomite. Trachyte and rhyolite porphyry dikes cut the gabbro, and larger intrusive masses of porphyry are numerous around the periphery of the gabbro. A few small replacement bodies of fluorite occur in limestone adjacent to some of the larger rhyolite masses.

SENIGON WELL, NOYAN, QUEBEC

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In 1942 a well was diamond-drilled to a depth of 2296 feet, near Noyan, 30 miles southeast of Montreal. An abbreviated log is as follows:

	Feet
Overburden	34
Utica shales	1076
No core	147
Trenton shales	867
Trenton limestones	172

The Trenton limestone is correlated with the St. Michel member of the Montreal formation. Particularly interesting is the great thickness of shales. Of these, the lower 867 feet is assigned to the Middle and Upper Trenton, whereas the upper 1076 feet is the equivalent of the Utica. No Lorraine beds occur here, hence the maximum thickness of the Utica remains in doubt. Its great thickness, 1076 as opposed to 300 at Montreal, is attributed to its marginal position on the Appalachian geosyncline. This same condition, plus increased argillaceous sedimentation beginning in Middle Ordovician time,

is considered responsible for the 867 feet of shales representing all post-St. Michel Trenton beds. Graptolites are the commonest fossils in the shales, and 12 species were used in zoning that part of the core.

METAMORPHISM OF COAL BY PERIDOTITE DIKES IN SOUTHERN ILLINOIS*

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While studying the effects of igneous intrusions on bituminous coal in southern Illinois, a method was developed whereby a close approximation could be made of the temperature involved during the intrusion.

Field investigations in a strip mine where a mica peridotite dike and adhering natural coke had been uncovered showed that the widths of zones of metamorphosed coal are small—in one instance only 12 to 14 inches adjacent to a dike 18 inches thick, that the zone is usually wider adjacent to larger dikes, but that no direct correlation exists between the size of the intrusive and the width of the metamorphosed zone.

Through differential thermal analyses of natural coke samples taken at measured intervals from the contact of an 18-inch thick dike, and comparison of the results with those obtained from analyses of normal coal samples preheated to known temperatures, cooled, and then rerun, estimates were made of temperatures to which coal at various distances from the dike had been heated.

At more than 4 or 5 inches from the contact, coal was insufficiently altered to permit estimates by thermal methods, and thin-section studies were used.

A maximum temperature of 600°C immediately adjacent to the dike is estimated, with rapid decrease outward.

SOME STRUCTURES OF THE EASTERN TOWNSHIPS OF QUEBEC

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The Oak Hill series (Lower Cambrian), first described by T. H. Clark in Sutton map area, has been traced northeast beyond Danville, Quebec. The basal member of this series is the Tibbit Hill lava. In 1952 a new member, a black graphitic limestone, was proved to lie at the top of the Oak Hill group in Canada.

The Oak Hill series is bounded on the west by the Oak Hill thrust, which brings it into contact with the Philipsburg series of Ordovician age. This thrust is an overthrust in Sutton map area and farther south in the United States, but changes its dip to become an underthrust at Brome Mountain and farther northeast.

In Sutton and Orford map areas the Oak Hill series is broken, near the east boundary of the Tibbit Hill lava, by the Brome underthrust. East of this underthrust lie the schists of the Sutton Mountains, with an apparently anticlinal structure.

In Richmond map area the Brome underthrust dies out. At the same time the deformation of the schists of the Sutton Mountains decreases, and they can be recognized as members of the Oak Hill succession. Their areal arrangements indicate that the true structure of the schist band in Richmond map area is that of a syncline.

Just east of the axis of this syncline appear the thick-bedded impure quartzites of the Caldwell group. The evidence at hand indicates that the contact is an overthrust from the east.

The apparently anticlinal structures of the schist band, in Richmond map area at least, are clearly produced by the overthrusts from each side.

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ISOTOPIC GEOCHEMISTRY OF HOT SPRINGS

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Many geochemical and geological problems require data on the rate of transfer of volatile materials from the interior to the surface of the earth; it is difficult to discuss the mechanisms involved without some estimate of the amounts of juvenile material being added to the surface at the present time. An attack on this problem has been begun by the method of isotopic analyses of carbon, oxygen, hydrogen, and nitrogen in the gases, waters, and deposits of thermal areas, and in igneous rocks.

Five areas have been studied: Yellowstone Park; Steamboat Springs, Nev.; Lassen Park, Calif.; The Geysers, Calif.; and Larderello, Italy. Yellowstone Park appears to contain the smallest proportion of magmatic components; the isotopic composition of the various phases is entirely in accord with a limestone origin for the carbon and a meteoric supply for the waters. In other areas the isotopic analyses indicate varying proportions of magmatic constituents which appear to be greatest at The Geysers. It appears that such areas can be used as successive approximations to determine whether juvenile carbon has the composition of carbon in igneous rocks or of mean surface carbon; this determination is important because an estimate of the degree of constancy of the rate of supply through geologic time can be derived from it. The data indicate that diamonds do not have the isotopic composition of primary terrestrial carbon.

GEOLOGY OF COAL IN ALBERTA, CANADA

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Coal in Alberta is found in the following five geological formations: Kootenay and Luscar formations of Lower Cretaceous age, Belly River and Edmonton formations of Upper Cretaceous age, and the Paskapoo formation of Lower Tertiary age. These coals are mined in the eastern Rocky Mountains, the foothills belt, and the plains. In general, mountain coal has semianthracite and bituminous rank; foothills coal is bituminous; and plains coal is subbituminous and lignite.

According to the last coal survey made in 1947, Alberta has a recoverable reserve of 23,937,150,000 tons. Minable coal—that is, coal in seams 3 feet or more in thickness and at depths of less than 1000 feet on the plains and 2500 feet in the foothills—is 47,874,300,000 tons, made up of 34,437,630 tons probable coal and 13,436,560,000 tons possible. These reserves constitute 48 per cent of the total reserves of Canada.

Detailed surveys of coal seams on the plains show that their maximum extent is 4 to 5 miles in a direction normal to old shore lines. Some seams have been traced for greater distances parallel to old shore lines. It was further observed that the number of coal seams in the geologic section varies greatly within the same formation. Consequently, the tracing and correlating of coal seams without continuous outcrop or good marker control can lead to error. The correlation of coal seams in faulted areas as in the foothills and mountains is especially difficult.

UPPER LLANDOVERY (CLINTON) GRAPTOLITES FROM EASTERN GASPE*

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The striking similarity between eastern Appalachian and British Paleozoic faunas has long been recognized. This similarity has been demonstrated for the Silurian shelly facies but not for its grapto-

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litic facies. In eastern Gaspe, the oldest known Silurian sedimentary rocks are olive-green and dark-gray graptolitic shales. These are exposed on the south limb of the eastern part of the St. John River anticline. The occurrence of such characteristic species as *Monograptus turriculatus, M. exiguus, M. nodifer, M. pandus, Rastrites maximus,* and *Retiolites* sp. cf. *R. obesus* in these shales is direct evidence for a precise correlation with zones 22 and 23 of the British graptolite succession. Recognition of these zones in Gaspe suggests that a wider application of the European Silurian graptolite zonal scheme is possible in the eastern Appalachian region.

YAKUTAT-FRANCISCAN TYPE ROCKS OF THE STATE OF WASHINGTON

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In Northwestern Washington are two areas of predominately clastic rocks very similar to the Yakutat Group, Lower Cretaceous?, of southern Alaska and the Franciscan-Knoxville Group, Upper Jurassic, of California. One area is in the central Olympic Mountains, the other in the western foothills of the Cascade Mountains in central King and Snohomish counties.

The rocks of the Olympic area are predominately graywacke, arkosic sandstone, argillite, slate, phyllite, and black slate breccia but include minor amounts of pillow lava, altered tuff, and argillaceous limestone. Altered remains of small Foraminifera resembling *Globigerina* are found in the limestone. Worm tubes very similar to *Terebellina palachei* Ulrich, known only from the Yakutat Group, have been found in the argillite and sandstone.

The rocks of the Cascade Mountain area are predominately argillite, graywacke, and arkosic sandstone but include minor amounts of black slate breccia, pillow lava, ribbon chert, siliceous limestone, and oölitic limestone. *Terebellina* tubes are apparently the only fossils.

The rocks of both areas have been complexly folded. The true thickness has not been determined but appears to be several thousand feet. The base of these rocks is not exposed. Tertiary lavas unconformably overlie both areas. The presence of these rocks in Washington furnishes further evidence of a late Middle Mesozoic geosyncline along the western coast of North America.

QUANTITATIVE SPECTROGRAPHIC ANALYSIS OF ROCKS USING A METHOD OF MUTUAL STANDARDIZATION

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The mutual standard method is based on the assumption that the intensity ratio of two spectral lines is a function only of the concentration ratio of the two emitting elements. Since the major elements compose essentially 100 per cent of common rocks, the formula

$$\%Al_2O_3 = \frac{100}{1 + \frac{\%SiO_2}{\%Al_2O_3} + \frac{\%TiO_2}{\%Al_2O_3} + \frac{\%Fe_2O_3}{\%Al_2O_3} - - - - - \frac{\%K_2O}{\%Al_2O_3}}$$

is used for the determination of alumina and thence the remaining oxides. Oxide ratios are found by plots (working curves) of $\frac{\text{Intensity, analysis line}}{\text{Intensity, Al 2652}}$ vs $\frac{\%\text{ analysis oxide}}{\%\ Al_2O_3}$. The lines used are Al 2652, Mg 2779, Mn 2801, Fe 2929, Si 2987, Ti 3088, Ca 3179, Na 3302, and K4044Å.

Analysis by this method may be performed on untreated powders in the d.c. arc, and all elements are determined simultaneously. Working curves prepared from chemically analyzed rocks allow determinations to be made over a wide concentration range, and use of standards of a similar nature to the analysis material insures accuracy. The relative deviation (% σ) of the method is 10 per cent.

A number of minor elements, notably Cu, Co, Mo, Ni, Pb, and Zr, may also be determined with the major elements.

Analytical time is less than 2 hours per triplicate analysis of an unknown rock.

TEMPERATURE AND THE DISTRIBUTION OF TRACE ELEMENTS

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The trace-element composition of a mineral can be considered as an equilibrium condition controlled by the major composition of the mineral, P-T conditions of formation, and the availability of trace elements.

Preliminary investigations have demonstrated that the hornblende, biotite, garnet, and chlorite Cu, Cr, Ni, and V contents decrease with increasing temperature. The major decreases of these elements—several thousand ppm for Cr and Ni, and several hundred ppm for Cu and V—seem to occur at the rock transformation from epidote-amphibolite to amphibolite facies. The hornblende and biotite Ti and Mn content increases with increasing temperature; however, these minerals are volumetrically small in the granulite and magmatic facies and may release Ti and Mn from the area. Zinc content, in the few samples analyzed for zinc, is uniformly low and may indicate release of Zn before epidote-amphibolite facies. Therefore, these facies changes and mineral reactions may be related to certain ore deposits of the indicated elements.

The anorthosite plagioclases may be the source of titanium in titaniferous iron ores associated with anorthosite. Anorthosite plagioclases are notably high in Ti, Fe, and Mg, most of which occurs as minute, opaque, exsolved, rodlike inclusions in the plagioclase. Granulation and recrystallization of the palgioclases are accompanied by notable decreases in Ti and often Fe and Mg in the four anorthosite areas studied.

Work on the trace-element behavior in pyroxenes, olivines, muscovites, epidotes, feldspars, and on other trace elements is in progress.

TYUYAMUNITE, CARNOTITE, AND SENGIERITE

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The following data were obtained by Weissenberg and precession methods; all lengths given in Å to ± 0.3 per cent.

Tyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot 6\text{–}8H_2O$, Mesa County, Colorado: orthorhombic, $a = 10.63$A, $b = 8.36$A, $c = 16.96$A; Pna*; pseudo Pnan (D_{2h}^6); Z = 4; G = 3.92 (obs.). Potassium replaces calcium; the Ca/K atomic ratio is 1.57 (analysis by U.S.G.S.).

Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 2/3H_2O$, from Cane Spring Pass, near Moab, Utah: monoclinic, $a = 10.47$A, $b = 8.41$A, $c = 6.91$A, $\beta = 103°40' \pm 10'$; $P2_1/a$ (C_{2h}^5); Z = 2; G = 4.70 (obs.). The cell dimensions of synthetic anhydrous carnotite reported by Sundberg and Sillen are similar, except $c = 6.59$A. The water of hydration should therefore be located between the structural layers (001). Carnotite twins by reticular pseudo-merohedry (index 3, obliquity *ca.* 1°); twin and composition plane (001).

Sengierite, $Cu(UO_2)_2(VO_4)_2 \cdot 8\text{–}10H_2O(?)$, from Haut Katanga, Belgian Congo, previously reported by Vaes and Kerr as orthorhombic: monoclinic, $a = 10.62$A, $b = 8.10$A $c = 10.11$ A, $\beta = 103°40' \pm 5'$ (gon.); $P2_1/a$ (C_{2h}^5); Z = 2; G = 4.41 (obs.).

Sengierite gives sharp x-ray reflections, whereas tyuyamunite and carnotite give streaky reflections indicating disorder in their crystal structures—the normal to the uranyl-vanadate layers describes a small-angle cone around the normal to the cleavage (001). This is ascribed to the weak bonding of Ca^{++} and K^+, a hypothesis supported by similar observations on the analogous phosphates: sharp

spots from meta-torbernite from Cornwall, England; streaky reflections from meta-autunite from Lauter, Saxony.

SUCCESSION OF EOCENE FLORAS IN NORTHWESTERN WYOMING

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Analyses of new collections of plants from northwestern Wyoming indicate a succession of distinctive floras, not previously recognized in this region.

An Early Eocene flora from the Willwood formation of the Big Horn Basin consists of about 45 species indicative of a lowland, humid, subtropical environment. Only 3 Willwood species occur anywhere in the Paleocene, whereas 32 are known from the Wilcox group of the Gulf Coast Province.

Floras of Middle Eocene age include about 30 species from several localities in the "Early Basic Breccia" of the eastern Absarokas, and about 15 species from the Tatman formation of the Big Horn Basin. These floras, essentially similar to that of the Green River formation of Wyoming, indicate lowland, humid, warm-temperature conditions. The transition from the Willwood flora facies may have occurred before Middle Eocene time.

A florule from the type locality of the Late Eocene Tepee Trail formation of the southern Absarokas shows similarity to the more temperate flora of the Green River formation of Colorado and Utah, confirming the suspicion that the latter, which differs from the type Green River flora, may also be of Late Eocene age.

A flora collected from the reported Eocene sequence near Dubois, Wyoming, contains about 30 species whose affinities are mainly with humid subtropical Pacific Coast floras which have been dated as Late Eocene to Early Oligocene.

These early Tertiary floras from northwestern Wyoming indicate that associated deposits were laid down in subsiding lowland basins in a region of moderate relief.

GLACIAL DEPOSITS PLOTTED FROM AIR PHOTOGRAPHS OF QUEBEC-LABRADOR

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Air photographs of the Quebec-Labrador Peninsula north of 50° latitude have been examined with the support of the Arctic Institute of North America.

Drumlins and eskers, in general parallel, form a striking pattern which can best be described as radiating from Ungava Bay in all directions across the whole peninsula. In view of a few conflicting reports of field evidence and the conceivability of some other explanation, it is only tentatively suggested that the Quebec-Labrador ice may have flowed out from Baffin Island.

Drumlins with N-S orientation, probably formed by another lobe, occur south of James Bay.

Other features plotted were beaches, proportion of outcrop, foliation, bedding, and linears in the bedrock marking joints or faults.

GLACIAL FEATURES BETWEEN THE MACKENZIE RIVER AND HUDSON BAY PLOTTED FROM AIR PHOTOGRAPHS

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Eskers, direction of drumlins, and some beaches have been plotted for much of Keewatin and eastern Mackenzie Districts. The directions of eskers, drumlins, and published striae parallel one another. South of a disturbed zone between Eskimo Point and Coppermine the directions fan out

to south and west. Farther north the flow, probably formed by another ice sheet, swept from Hudson Bay to the Arctic Coast.

Near the Mackenzie River the junction with Cordilleran ice caused an abrupt change in direction to northwest. This flow apparently formed a huge terminal moraine immediately east of the Mackenzie Delta.

TWO LATE WISCONSIN INTERSTADIAL DEPOSITS FROM ONTARIO, CANADA

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Of the two deposits, one is from the shore of Lake Erie 9 miles west of Port Stanley, Ontario;* it consists of lacustrine silt and gyttja and is covered by two till beds which up to now have been correlated with the lithologically similar early and late Cary tills of northern Ohio. C 14 date of the gyttja (10,900 ± 400) suggests a later age—the Two Creeks interval—for this interstadial deposit. Pollen analysis reveals the existence of forests along Lake Erie consisting principally of jack-pine and spruce.

The other deposit is from North Bay and consists of a peat bed covered by a thin layer of very bouldery till. Pollen analysis records growth of birch, hemlock, pine, spruce, fir, oak (in a descending order of abundance) and some elm, linden, beech, and alder. The results of pollen analysis suggest that the peat was deposited during the postglacial thermal maximum or slightly later.

If the C 14 dating of the first interstadial deposit is correct, the retreat of Wisconsin ice from Ontario was later than assumed by most Pleistocene geologists, with Mankato ice twice occupying the Lake Erie basin and a readvance of ice down to North Bay during the "little ice age" after the postglacial thermal maximum.

CHARACTERISTICS AND GENETIC RELATIONSHIPS OF A CARBONACEOUS SUBSTANCE FROM THE CAMBRO-ORDOVICIAN OF THE MOHAWK VALLEY, NEW YORK

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A unique carbonaceous substance, physically and chemically like anthracite, but genetically related to the bitumens, occurs near Canajoharie in the Mohawk Valley, New York. It is found as partial vug fillings with quartz and calcite and as disseminations, principally in the Upper Little Falls dolomite of Cambrian age. Because of its presence as colloform coatings within some quartz crystals and the more usual deposition of quartz on top of the carbonaceous material, the alteration from a bituminous liquid to its present form appears to have occurred just before and during the beginning of deposition of the associated quartz crystals. High pressures are believed to be unimportant in its formation because the pockets were only partially filled with bituminous material during most of the carbonization. Since thermal and hydrothermal effects are absent in the area, the alteration is believed to have been caused by oxygenated ground waters beneath erosion surfaces either during or after deposition of the Paleozoic formations. The substance probably approaches a theoretical carbon end member of the generalized reaction: petroleum → asphalt → carbon. Observations of the slightly curved upper surfaces of the carbonaceous substance in partially filled pockets reveal that the carbonization occurred between periods of folding. The genetic implications of the carbonaceous source material and its areal distribution with reference to the Adirondack Arch constitute a problem of potential economic interest.

* The study of this interstadial deposit was made possible by a grant of the Research Council of Ontario.

STRATIGRAPHY AND PALEONTOLOGY OF THE NOATAK AND ASSOCIATED FORMATIONS, BROOKS RANGE, ALASKA

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The thick clastic Noatak formation of P. S. Smith, underlying the Lisburne limestone (Mississippian) in northern Alaska, is here subdivided into five units. Three of these formations occur in the western Brooks Range: an Upper Devonian siltstone-shale; the Noatak formation (restricted) (Upper Devonian and lower Mississippian); and a lower Mississippian ferruginous calcarenite. In the central Brooks Range, the Upper Devonian siltstone-shale is overlain by a thick chert conglomerate, approximately equivalent to the Noatak formation (restricted). The conglomerate is succeeded by a lower Mississippian limestone-shale unit.

The chert conglomerate may have formed in a belt of fluctuating marine and nonmarine conditions, the source being a regolith developed on a low-lying northern land mass. In early Mississippian time, normal marine conditions were re-established by gradual encroachment of the sea from the west.

The formations of Late Devonian age are considered correlative with the Imperial and Hay River formations of Canada. Early Mississippian faunas resemble those of the Banff formation in Alberta and the Lodgepole limestone of Montana. The youngest faunas discussed seem correlative with those of the lower part of the Rundle formation of Alberta and the Mission Canyon limestone of Montana. The Alaskan faunas also resemble the faunas of the Kassin, Russakov, and, possibly, lower Ishim beds of northeastern Kazakstan.

TECTONIC RELATIONS OF NORTH AMERICA AND SOUTH AMERICA

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The Pacific and Atlantic marginal belts of orogeny in Paleozoic time are believed to merge in central and southern Mexico and then as a single belt to swing eastward through Central America approximately to Jamaica and Hispaniola. Veering sharply southward from Hispaniola the belt includes the present submerged Beata Ridge and connects with the metamorphic core of the Venezuelan and Colombian Andes.

The major Mesozoic belt of orogeny is believed to extend down the peninsula of Baja California, through the Sierra del Sur of Mexico to the Costa Rica-Panama Isthmus and the Colombian and Ecuadorian Andes. It is marked throughout by great granitoid batholiths. Another belt of late Jurassic and Cretaceous orogeny extends eastward in Central America from the main belt and follows through the Greater and Lesser Antilles to Trinidad and Venezuela to join the main belt in Colombia. This belt makes a tight U-shaped pattern and is believed to mark two tectogenes for the most part, both of which formed in late Mesozoic time and probably one soon after the other. A third tectogene from Puerto Rico around the Lesser Antilles to the Leeward Islands is active today and probably formed in Eocene time. It lies outward from the late Mesozoic tectogenes. The available geophysical data (gravity anomalies and earthquake foci) are related to the geological information in analyzing the tectogenes. The eastern Caribbean basin is believed to be due to middle and late Tertiary subsidence, and the western Caribbean Basin to Cretaceous and early Tertiary subsidence. The Gulf of Mexico is postulated to have started to subside in Permian time.

A theory of orogenesis proposes asymmetrical convective flow in the mantle as the causative mechanism. The theory is applied to the Dutch East Indies and the Peruvian Andes as well as the Mediterranean region between North America and South America.

SEDIMENTARY ORIGIN AND STRATIGRAPHIC EQUIVALENCE OF THE SO-CALLED CRANBERRY AND HENDERSON GRANITES IN WESTERN NORTH CAROLINA

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The rocks that have been called Cranberry granite and Henderson granite in the metamorphic complex of western North Carolina have been found to be largely sedimentary in origin. Four specific field relations favor this conclusion: (1) At least 75 per cent of the outcrops of these rocks show primary compositional banding, (2) these rocks are interbedded with rocks of known sedimentary origin (*e.g.*, Carolina gneiss), (3) intrusive relations between the Henderson or Cranberry and the Carolina are absent, (4) the regional distribution suggests that the Cranberry and Henderson rock is the lower unit in the southwest-plunging synclinorium. This field evidence is supported by a microscopic study of zircons from these rocks that shows the common phases of the Cranberry and Henderson to be mostly sedimentary. Detailed mapping in the northwest corner of the Morganton quadrangle where the Cranberry and Henderson come together shows that along strike they grade from one into the other. The two formations therefore seem to be stratigraphically equivalent, and the minor differences in their composition may be attributed to facies changes in the original sedimentary sequence. The Cranberry and Henderson rock apparently underlies the Roan and Carolina complex in the Spruce Pine District and thus is older than that complex rather than younger as previously believed.

Pb^{210} METHOD OF AGE DETERMINATION

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The age of a uranium-bearing mineral can be determined by measuring the ratio of Pb^{206} to Pb^{210}. The Pb^{206} concentration is determined with the mass spectrometer. The Pb^{210} (RaD) concentration is measured by scintillation alpha counting the daughter Po^{210} (RaF). Calibration of the alpha counting system is achieved by counting the Po^{216} derived from known aliquots of radon. The method has several important advantages. The ratio Pb^{206}/Pb^{210} is insensitive to both radon leakage and uranium leaching. Pb^{210} ages on minerals from classical uranium localities are in good agreement with the "best" ages derived from other isotopic data.

CHEMICAL CONSTITUTION OF PALYGORSKITES AND PILOLITES

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Sepiolite minerals which might be considered as end members of the palygorskite and pilolite series are characterized by significant variations of their chemical composition. This may be expressed by the coefficient K corresponding to the varying ratio of $MgO:SiO_2$ in the chemical formulae of sepiolites. In the sepiolites studied by the author and other investigators the coefficient K covers the range from 1.0 to 0.60—*i.e.*, from $MgO \cdot SiO_2 \cdot 1.5H_2O$ to $6MgO \cdot 10SiO_2 \cdot 10H_2O$. Consequently the composition of the sepiolite minerals can be expressed by a series of formulae having the following $MgO:SiO_2$ ratios: 1.0, 0.88, 0.75, 0.66, 0.60, 0.50. An end member of the sepiolite series, $MgO \cdot 2SiO_2 \cdot 2H_2O$ (K = 0.50), was originally (1939) assumed by the author to be a hypothetical mineral and was actually discovered in 1949 in the Urals (Gerasimov, Grushko, Chirvinsky). These formulae of

the sepiolite series make it possible to explain the chemical constitution of palygorskites and pilolites. These minerals may be considered as products of an isomorphic isovalent replacement

$$Mg_3^{\cdot\cdot} — Al_2^{\cdot\cdot\cdot}$$

in the molecules of sepiolite minerals with different K values. The recalculation of molecular quantities in the analyses of palygorskites and pilolites after the replacement of $Al_2^{\cdot\cdot\cdot}$ through $Mg_3^{\cdot\cdot}$ enables us to demonstrate that the empirical chemical formulae of these minerals correspond quite exactly to the formulae of the sepiolite series. This point of view has been corroborated by x-ray investigations and by the thermal-analysis data. On the basis of x-ray data the mineral $MgO \cdot SiO_2 \cdot 1.5\ H_2O$ recently described as a new species by Ginsburg and Rukavishnikova and named "beta-cerolite" seems to be a typical sepiolite.

VEINS OF ALUMOSERPOPHITE IN SERPENTINITE ROCKS (NORTH CAUCASUS)

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Many serpentinite massifs of the North Caucasus are broken by fissures among which two pronounced systems have been ascertained: one of 310° NW. and the other 60° NE. Many of the fissures of both systems contain thin (1–3 cm) veinlets of semitransparent, in places opaline yellow and bluish-green serpophite. Along these fissures in the Beden serpentinite massif the formation of brown, bluish-green, and black serpophite veins may be observed. The thickness of these veins ranges from a few centimeters to 1 meter. The serpophite contains a significant amount of Al_2O_3 (7–10%). The chemical formula of this mineral is approximately $5(Mg,Al_{2/3}) \cdot 3SiO_2 \cdot 3H_2O$. It is expedient to call this mineral alumoserpophite. Thus according to the data of our investigations there are the following varieties of aluminum-bearing serpentines: alumochrysotile, alumodeweylite, alumoantigorite, alumocerolite, and alumoserpophite.

The presence of such a polar element as Al in serpophites is an illustration of Larsen's polarity law.

In many cases the veins of alumoserpophite contain grains of biotite, apatite, rutile, and zircon.

COMPOSITIONAL EVOLUTION OF A MAJOR MARBLE UNIT, GRENVILLE SERIES, NORTHWEST ADIRONDACK MOUNTAINS, NEW YORK

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Marble in the Balmat-Edwards area is at least 1800 feet thick and represents about one-sixth of the marble in and one-ninth of the thickness of the exposed Grenville series. A weighted average composition of marble inferred to be least altered includes 50 minerals, chiefly (volume per cent) dolomite, 42; calcite, 18; quartz, 16; diopside, 8; tremolite, 7; serpentine, 4; talc, 2. As oxides this represents (weight per cent) SiO_2, 28; MgO, 17; CaO, 25; CO_2, 27; other, 3.

Field studies suggest that premetamorphic (sedimentary?) amounts of MgO and CaO approximated present values, but that the mineral composition was (weight per cent) quartz, 15; dolomite, 80; other, 5. Major chemical changes during metamorphism were, therefore, doubling of SiO_2 and appreciable decarbonation. Most calcite probably formed during the (incongruent?) solution of dolomite by water-rich, alkali-silicate, magmatic fluids. These fluids deposited quartz and widely distributed magnesia, concentrating it into zones of tremolite, anthophyllite, talc, and serpentine. Principal premetamorphic accessories postulated are calcite, clay minerals, gypsum, and conceivably pyrite, H_2S, and methane.

Trace elements in least-altered dolomite beds include (modes of 40 analyses, in ppm) Sr, 200; Mn, 700; Ti, 20; Ba, 4; B, 20; Cu, 2. Comparison with other dolomites—some equally, some less metamorphosed, some roughly contemporary, some much younger—suggests that appreciable strontium diffused out of the dolomite during metamorphism about a billion years ago. One analysis

for lead, by Patterson, showed a concentration of 2.14 ppm with an isotopic composition exceptionally high in Pb^{207}. A possible explanation of the values is that both amount and composition of lead were modified during metamorphism by interchange of constituents in the dolomite with those in associated carbonaceous shales.

DEEP-SEA CORES AND CURRENTS IN THE PLEISTOCENE NORTH ATLANTIC

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Study of several hundred sediment cores shows that well-defined faunal zones occur in the Pleistocene section deposited along the path of the present clockwise current system of the North Atlantic. Three zones containing *Globorotalia menardii* in abundance are separated by layers in which the species is rare or absent. Correlation from core to core is confirmed by the remains of other organisms and by changes in the coiling direction of *Globorotalia truncatulinoides*. There is good evidence that the layers with few or no *G. menardii* were deposited during times of Pleistocene glaciation. However, no attempt is made here to identify them with particular glacial stages. It is noteworthy that these layers are as clearly defined in cores from the Equator and Caribbean as in the most northerly cores.

Recent distribution of *G. menardii* in the North Atlantic and Caribbean, as known from 400 widely scattered bottom samples, indicates that the clockwise current system of the North Atlantic is a more important factor in the distribution of the species than temperature alone.

Vertical distribution of *G. menardii* in the cores gives no evidence of a southward shift of the current system during Pleistocene glacial stages. Instead, drastic reduction of volume of flow or even cessation of flow is indicated by the simultaneous disappearance of *G. menardii* throughout the North Atlantic.

SYNTHESES AND STABILITY OF THE PHLOGOPITES

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A one-layer monoclinic (1M) or a three-layer trigonal (3T) hydroxyl-bearing phlogopite has been synthesized. A curve through the points 840° C.—1,000 psi water vapor pressure, 995°—5,000 psi, 1025°—10,000 psi, 1050°—15,000 psi, 1080°—30,000 psi, and 1105°—75,000 psi mark the upper limit of stability of phlogopite. Above this curve the stable phases are forsterite + leucite + orthorhombic $KAlSiO_4$ + vapor. These same phases form metastably at temperatures immediately below the curve, particularly at low pressures.

The phlogopite forms quickly at the higher temperatures, and grows very slowly at the lower temperatures. At the lowest temperatures a completely disordered mica (1Md) grows which is believed to be equivalent to the trioctahedral clay micas. It is not possible to distinguish the 1M and 3T polymorphs on the basis of powder X-ray diffraction patterns; however, the synthetic phlogopite is not 2M. A natural 2M can be transformed to a 1M or a 3T at high temperatures. The phlogopites from lavas are one-layer monoclinic (1M); however, 1M phlogopites are also formed in metamorphosed limestones. No clear relationship between the temperature of formation and the type of stacking in natural phlogopites has been observed.

Eastonite was synthesized, and its decomposition products are forsterite + leucite + orthorhombic $KAlSiO_4$ + spinel + vapor. Mahadevite (1M) is close to eastonite in composition and does not lie midway on the phlogopite-muscovite join.

Phlogopite appears on the liquidus in the synthetic "haplogranite." The formation of phlogopite (and biotite) and the absence of muscovite in lavas are accounted for by their stability curves.

Data have also been obtained on the phlogopite-muscovite, phlogopite-eastonite, and phlogopite-annite joins.

CRYSTAL STRUCTURE OF KVO_3

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Anhydrous potassium metavanadate, KVO_3, forms colorless crystals on precipitation from a water solution containing KOH and V_2O_5 in the mol ratio of 2 to 1, at a pH of 7 to 8. The crystals are orthorhombic, space group Pmab, with a = 5.69 A, b = 10.82, c = 5.20, the unit cell containing $4KVO_3$. The structure contains infinite chains stretched along the c axis, with VO_4 tetrahedra linked by corners in a manner similar to the silicate tetrahedra in diopside. The structure is analogous to that proposed for NH_4VO_3 by Lukesh. The chain linkage is contrasted with the fivefold co-ordinated chain linkage found in $KVO_3 \cdot H_2O$, which forms under the same conditions as KVO_3.

ALTERATION PROCESSES IN MONTROSEITE

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Montroseite, (V,Fe)O(OH), has been shown to have a structure analogous to that of diaspore, AlO(OH). Crystals of montroseite give multiple x-ray patterns, showing one sharp orthorhombic lattice corresponding to the host crystal, and a pair of diffuse lattices of similar symmetry and dimensions in parallel orientation. The more prominent of the diffuse phases is interpreted as a metastable form of VO_2, resulting from oxidation of the host crystal. The concept of an alteration process involving a migration of ions and electrons through an undisturbed oxygen framework is supported by a Fourier analysis of x-ray intensities of the sharp and diffuse lattices and by chemical and thermal information. The postulated alteration mechanism is illustrated by certain other examples, notably the alteration of lepidocrocite to maghemite, and goethite to hematite.

TURBIDITY-CURRENT TRANSPORTATION OF SEDIMENTS IN THE ATLANTIC

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The mean thickness of the layer of unconsolidated sediment in the Atlantic is known from seismic refraction studies and from the dispersion of earthquake surface waves to be 0.5 to 1 km. It is underlain by rock believed to be basaltic, in which the speed of seismic waves is 6.4 to 7.0 km/sec. Beneath some 5 km of this rock is the Mohorovičic discontinuity.

The extensive abyssal plains which constitute the bottoms of most of the major Atlantic basins show alternating beds of clay and sand. The latter are interpreted as turbidity-current deposits. Many smaller basins have flat floors underlain by similar alternating beds, corresponding to turbidity-current deposition which in many cases has reached and overflowed a sill. On all steep slopes investigated there are numerous exposures of older beds which have been kept free from recent sediments by the turbidity currents, or the slumps which generate them. Only on gentle rises do we find considerable thicknesses of sediment which are unaffected by turbidity currents. Seismic-reflection studies demonstrate that this correlation between topography and sediment type extends far deeper than the coring tubes have reached. The topography and sediments in submarine canyons which have been shown to extend far out into deep water prove that these are the channels through which the turbidity currents have flowed. The cable breaks associated with the Grand Banks earthquake of 1929 demonstrate that a major turbidity current flowed in historic times.

Trapping of turbidity-current sediments by the long narrow trenches associated with island arcs causes rapid filling of these trenches and is responsible for the great accumulations of sediments near

continental borders and for the absence of a thick layer of sediments in the ocean basins. It is suggested that granitization of sedimentary accumulations is responsible for the growth of continents and that contamination of the underlying basaltic magma by the sediments produces the andesitic lavas. Recent findings of oceanic crust in the central basins of the Caribbean and the Gulf of Mexico deny the possibility that these have resulted from subsidence.

This mechanism of continental growth is in agreement with facts of peripheral deep earthquakes, gravitational equilibrium of the earth's crust, and propagation of earthquake surface waves in continental layers.

MURDOCHITE, A NEW COPPER LEAD OXIDE

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Chemical analysis and x-ray structural studies (*see* abstract by C. L. Christ and J. R. Clark in this issue) establish as a new species a copper lead oxide from the Mammoth Mine, Tiger, Arizona. The percentage composition, 67.24 CuO, 30.53 PbO_2, 0.17 Fe_2O_3, 0.05 SiO_2, and 1.11 Insol. yields the formula Cu_4PbO_6. The specific gravity is 6.465 at 4°C. The mineral forms in tiny lustrous black octahedra associated with wulfenite, dioptase, willemite, and fluorite.

The new mineral was found by the late Percy W. Porter of Cavecreek, Arizona and at his request is named in honor of Professor Joseph Murdoch of the University of California at Los Angeles.

SOME DATES AND SUBDIVISIONS OF THE CANADIAN SHIELD

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Ages have been determined for more than 100 mineral specimens collected from the Canadian Shield by the Geological Survey of Canada and mining companies. The three methods employed have been the isotopic analysis of lead extracted from either uranium or lead ores or the analysis of potassium-bearing minerals for potassium and radiogenic argon. Comparisons show general agreement among the different methods and with the results of other workers.

The ages combined with other geological data suggest that the Archean gneisses are up to two billion years old and are divisible into provinces each active during a limited period averaging about three hundred million years. Provinces formed two to three billion years ago contain Keewatin type rocks.

Each Archean province may have one or more Proterozoic basins associated with it according to a definite pattern.

A few dates and general comparisons with other continents have been established.

RADIOACTIVITY OF THE HELIUM-BEARING FORMATIONS OF THE TEXAS PANHANDLE REGION

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The discovery of radon in some of the helium-bearing natural gas in the Texas Panhandle gas field points out the desirability of determining the distribution and occurrence of radon and associated radium, uranium, and helium in formations containing natural gas. The radon content of about 1200 producing gas wells has been measured, mostly in the Panhandle field. Concentrations from less than 1 to about 700×10^{-12} curies of radon per liter (S.T.P.) have been observed. The highest concentration of radon usually occurs along the fringes of structural highs. Theoretical analysis of radon

measurements under conditions of transient gas flow indicates that the measured radon may originate in the immediate vicinity of the bore in most wells. This result is tentatively confirmed by gamma-ray logs in two wells, but so far it has not been possible to obtain adequate samples of the gas-producing beds to determine the radon source. Samples of spent liquor from the acidizing of one well show great excess of radium over uranium. Small grains of uraniferous asphaltite and radioactive petroleum residues are disseminated in drill samples of dolomite from beds well above and within the gas-producing formations. Radon concentration in the gas is not enough to account for the high helium content. The research is being continued, and comprehensive studies of subsurface geology of this and several other gas fields are in progress.

ABUNDANCE OF S^{33} AND S^{34} IN SOME NATURAL SOURCES OF SULFUR

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An investigation of the abundance of S^{33} and S^{34} in natural sulfur compounds has been undertaken as part of a study of the origin of Gulf Coast Sulfur deposits.

The abundance expressed as S^{33}/S^{34} was measured on sulfur dioxide in a Nier type, single collector, mass spectrometer.

A suite of about 25 samples from the Newgulf Salt dome showed that the S^{33}/S^{34} ratio for the sulfur from the sulfate was about 1.4 per cent lower than that from elemental sulfur. It was also shown that the ratio S^{33}/S^{34} is not constant in either the sulfate or the native sulfur. Variations of as much as 4 per cent have been found in both forms. The S^{33}/S^{34} from sulfate in the caprock appears slightly lower than in the salt mass suggesting preferential leaching. At the Newgulf Salt dome the S^{33}/S^{34} in the H_2S of the bleedwater, in the pyrite of the caprock, and in the native sulfur fall within the same range. This suggests that the last step in the formation of the native sulfur is the oxidation of the H_2S.

A core from near Barreno, Mexico, in which elemental sulfur and gypsum were closely associated showed the S^{33}/S^{34} ratio from the gypsum to be only 6 per cent lower than the elemental sulfur. Laboratory experiments with the sulfur-oxidizing bacteria *Thiobacillus Thiooxidans* showed no fractionation effects.

In sea-water sulfate samples from the same location the sulfur isotope ratio is the same at the surface and at a depth of 7600 feet.

ACTIVE SAND DUNES IN THE KOBUK RIVER VALLEY, NORTHWESTERN ALASKA*

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Two areas of active sand dunes occupy 50 square miles in the central part of the east-trending Kobuk River valley, northwestern Alaska. Small active blowout dunes are scattered over other parts of the valley. Stabilized dunes cover more than 300 square miles.

Both the active and the stabilized dunes exhibit a variety of forms, most of which are genetically related to the parabolic type. Vegetation-free, barchanlike dunes commonly occur where moving sand encounters streams or springs. The overall shapes of the dune areas and the morphology and bedding of individual dunes indicate southeast and east winds as the effective present and past dune-forming winds.

Mean annual precipitation is probably about 13 inches, about half of which falls in summer. Fall, winter, and spring winds are mostly easterly; summer winds are both easterly and westerly, with southwest winds prevailing. Exceptionally dry summers are believed to have more frequent easterly

* Publication authorized by the Director, U. S. Geological Survey

winds. Summer field observations show that steady easterly winds cause active dune migration. Movement of moisture-saturated sand, usually associated with southwest and west winds, is very slight. Post-frontal, gusty northwest winds scatter sand irregularly without controlling dune migration.

The original source of the sand is mostly from the tremendous quantities of sandy outwash and alluvium in the Kobuk River valley. Previously deposited dune sand is the immediate source of most of the currently active dunes. The degree of dune activity and extent of vegetation cover have varied with climatic changes and occasional fires.

DISTRIBUTION OF URANIUM DEPOSITS IN THE SHINARUMP CONGLOMERATE OF THE COLORADO PLATEAU

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On the Colorado Plateau the Upper Triassic Shinarump conglomerate contains many important uranium deposits. A reconnaissance study of the deposits, made to appraise the potentialities of areas underlain by the Shinarump conglomerate, yielded tentative conclusions.

The Shinarump consists mainly of light-colored sandstones and conglomerates in channel fills and even-bedded layers. Uranium minerals impregnate the rock. Deposits range in size from a few tons to many thousand tons and seem to be localized mainly in three belts.

In Monument Valley, northeastern Arizona and southeastern Utah, a belt of favorable ground at least 4 miles wide and 40 miles long trends northwestward. The deposits are localized in deep channels, which also trend northwestward. In White Canyon, southeastern Utah, a belt of favorable ground averaging 5 miles in width and about 30 miles in length trends northeastward. The deposits in this belt occupy shallow channels. In central and eastern Utah, significant deposits and geologically favorable ground are alined in a belt 10 to 20 miles wide and about 100 miles long. The deposits occur in even-bedded sandstone in the eastern and western parts of the belt and along the transition zone of facies changes from coarse to fine sediments in the central part of the belt. An altered zone, colored purple and white, in the Moenkopi formation and Shinarump conglomerate has an areal distribution that roughly coincides with this favorable belt.

These belts, representing about 10 per cent of the areal distribution of the Shinarump, are more favorable for prospecting than the remainder of the region. Even in these favorable belts, deposits are sparsely scattered.

SEDIMENTARY FILL IN TWO MEXICAN FOREDEEPS

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Extensive bathymetric investigations of the Cedros Deep off Baja California and the northwest portion of the Acapulco Trench indicate that these near-shore depressions are remarkably flat-bottomed. Elongated flat areas along the trench axis are separated by ridges or abrupt breaks in slope. Flat areas at lesser depths imply damming behind basement irregularities. Gently sloping aprons at the base of the steep trench flanks and knolls which protrude a few tens of fathoms above the flat bottoms also suggest sedimentary fill.

Seismic-reflection shooting indicates that one major subsurface reflecting horizon is present in both the Cedros Deep and the Tres Marias Basin at the northwest end of the Acapulco Trench. A reversed refraction profile in the Cedros Deep yielded a velocity of sound propagation of about 6.2 kilometers/second for the material below this horizon. If in each locality the fairly continuous echo returns from the sediment-basement contact, reflection-shooting results indicate that the sediments thicken slowly from the west side of the trench to an observed maximum near the east flank. This contact has not been traced across the steep east near-shore flank. In both regions a minimum bottom

echo to sub-bottom reflection time interval of 0.4 second was measured near the west flank of the trench. The maximum time interval measured from the Cedros profile was 1.6 seconds, as compared to 2.1 seconds for a profile near the Tres Marias. Both profiles include local reversals, indicating that the basement has a relief of several hundred feet.

SYSTEM FeO-SiO_2-H_2O

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Phase-equilibrium relationships are presented for the system FeO-SiO_2-H_2O. Syntheses are reported for wustite, magnetite, fayalite, greenalite, minnesotaite, grunerite, and hydrated ferro-ferrisilicates of the chlorite and mica families. In a nonoxidizing hydrothermal environment fayalite undergoes serpentinization to form greenalite below 250°C. Greenalite thermally decomposes to fayalite and minnesotaite above 470°C. The upper limit of stability for minnesotaite is placed at 480°C.—minnesotaite decomposes to fayalite and quartz, and grunerite appears as a metastable intermediate phase. Fayalite and silica coexist from 480°C. to the limits of experimentation at 925°C. The iron pyroxene, "ferrosilite," was not identified. Distinction is made between the stability relationships observed in a closed, nonoxidizing hydrothermal environment and those to be expected in an open or circulating hydrothermal system.

SUBSURFACE PRECAMBRIAN ROCKS IN WEST TEXAS AND SOUTHEAST NEW MEXICO

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Study of cores and cuttings from 325 wells that penetrate basement rocks in west Texas and southeast New Mexico indicates (1) a central stable mass or craton composed mostly of plutonic rocks but containing minor patches of metasedimentary and meta-igneous rocks; (2) volcanic rocks, mostly rhyolite porphyry, of probable late Precambrian age overlying the craton to the northwest; (3) a late Precambrian mobile belt composed of metasedimentary and intrusive igneous rocks bordering the craton on the southwest (including Precambrian rocks exposed in the Van Horn area); and (4) a major Precambrian structure, possibly a mobile belt, roughly congruent with the younger Wichita structural trend in north-central Texas and southwest Oklahoma. Exposed Precambrian rocks in the Llano uplift in central Texas are part of a great bulge of the craton which acted as a buttress and influenced subsequent orogenic development.

Age determinations on the Baringer Hill pegmatite and the Iron Mountain magnetite mass in the Llano uplift check at about 1050 my, and probably (1) the bulk of the plutonic rocks of the craton are older, and (2) the volcanic rocks, which seem to be flows on the craton, and the rocks of the mobile belt thrust against the craton to the southwest are younger. Buried Precambrian rocks in north-central Texas that roughly coincide with the Wichita trend are metasedimentary rocks and igenous rocks different from those of the craton. These rocks are on the south flank of a striking gravity anomaly that outlines the Wichita structure.

DAMSITES OF THE NEW YORK CITY WATER SUPPLY SYSTEM

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The Board of Water Supply of the City of New York has investigated many damsites in the southeastern part of New York State by means of test borings. Three dams have been constructed, and others have been proposed.

The region has been glaciated. Valleys formed in preglacial time have been partially filled with soils of glacial and recent origin. The deposits include till, modified drift, and lake sediments. The valley fill in some cases is known to exceed 350 feet in thickness and, at one site, may exceed 500.

The deposits vary in kind and permeability. The variations affect the design and construction of dams. Because of the width of the valleys and the abundance of glacial soils, earth dams are the most economical type. The investigations indicate that, in the Catskill region, where there is relatively little difference in the resistance of the bedrock to weathering and erosion, and where faulting is of minor importance, there are only minor variations in the cross-sectional areas of a valley eroded into bedrock, and that, irrespective of local superficial variation in profile caused by glacial deposits, the preglacial "hydraulic area" remains approximately the same.

CLASSIFICATION AND CORRELATION OF DIOCTAHEDRAL MICAS AND HYDROUS MICAS

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The method for calculating formulas for montmorillonites from analyses, suggested by Marshall, and the fractional notation used by Ross and Hendricks for writing formulas for montmorillonites is extended to the dioctahedral micas and hydrous micas, which have the same 2-1 layer structure. From formulas so calculated the charges on the tetrahedral and octahedral layers can be calculated. The sum of these charges should agree closely with the sum of the external cations and provide an internal check on the purity of the sample and the accuracy of the analysis.

Such formulas, with a notation of charge on tetrahedral and octahedral layers, provide a means for comparing the composition of micas and hydrous micas and reveal relationships not otherwise evident. From the muscovites and sericites, in which almost all the charge is on the tetrahedral layer, there is a continuous shift in the relationship between tetrahedral and octahedral charge through the phengites and glauconites to the celadonites, in which the charge is almost wholly octahedral. The micas and hydrous micas can be classified, therefore, according to their tetrahedral-octahedral charge relationship. Such a scheme of classification permits the correlation of specimens containing unusual constituents, such as manganese, vanadium, chromium, etc. And many specimens that have been given specific mineral names are shown to be merely steps in the shifting of the seat of the charge or in the degree of hydration.

SIMPLE METHOD FOR THE DETERMINATION OF THE PLAGIOCLASE FELDSPARS

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Precise refractive index data on synthetic plagioclase feldspar glasses have been available for over 40 years. However, no routine method based upon these data has come into general use for the determination of the natural feldspars. Such a method possesses certain advantages over the many other procedures now followed. Its theoretical accuracy is about twice that obtainable with established refractive index methods. Index determinations, involving no particular refinements of technique, were made on the glasses of eight chemically analyzed natural plagioclase feldspars. The anorthite contents derived from these data agreed with those calculated from the chemical analyses within about 2 per cent. The method is simple and rapid, and calls for no costly equipment. It is therefore recommended for inclusion among the standard methods for the determination of the plagioclase feldspars.

DETERMINATION OF THE MODULUS OF ELASTICITY OF ROCKS FOR PRESSURE TUNNELS AND SHAFTS

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The only reliable means of determining the modulus of elasticity of rocks for pressure tunnels and shafts is to make a test on the rock in place by a small test tunnel. This is often not feasible or practical because of the inaccessibility of the rock along the tunnel route, the fact that more than one type of rock is involved, high expense, and time required. Nevertheless, more important projects should have at least one representative field test on the rock in place, if possible.

Test results from core samples usually give values considerably higher than the rock in place and must be used with caution. For most igneous and metamorphic rocks the values obtained from core samples may average as high as 100 per cent above field conditions. This value may even be excessively high if the rock is closely jointed or altered or if the rock is an extrusive type.

Schistosity, foliations, and bedding have less influence than jointing. If the joints are clean and have an opening of $\frac{1}{100}$th of an inch or more, careful, high-pressure grouting may improve the elasticity properties and reduce the permanent deformation.

CARIBOU ERUPTIVE COMPLEX, AN INTERPRETATION IN TIME AND SPACE

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The Caribou complex is located in the Canadian shield 2 miles west of Loring, Ontario, where it intrudes granite gneisses. Its shape is that of a lopolith, the map picture presenting a funnel tilted to the west and planed off by erosion. Structural, geophysical, and petrographic evidence indicates that the magma was emplaced from the east. The complex is mostly norite with local peridotite and pyroxenite facies; granodiorite forms the upper facies of the intrusive. Throughout, the feldspars and pyroxenes of the norite show granulation and mortar structure. They show extensive replacement by hornblende and biotite which are locally intergrown with pyrite, pyrrhotite, and titaniferous magnetite. Garnet and quartz form reaction rims separating feldspar and pyroxene in the norite; in the olivine-bearing rocks hypersthene, spinel, and a diopside-spinel symplectite separate the olivine from the feldspar. The intrusive shows cryptic layering with gradual Fe and Na-Si enrichment toward the west on which is superimposed a rhythmic layering of pyroxene and feldspar.

Consolidation of the intrusive was followed by extensive jointing, and granite pegmatites ascended many of the fractures. Metasomatism of the norite by the pegmatites gave rise to quartz diorite with a diablastic texture in areas adjoining the pegmatites and may be responsible for the extensive biotite, hornblende, and reaction-rim formation in the complex. Late-stage faulting broke up the complex into seven blocks. Some of these faults bear nickeliferous pyrrhotite; mineralization thus post-dates the main igneous activity.

USE OF ZONE OR BAND THEORY IN PROBLEMS OF SULFIDE MINERALOGY

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The metallic or semimetallic characteristics of many sulfide minerals, demonstrated by such properties as ductility, metallic luster, and low electrical resistivity, are evidence of the metallic nature of their chemical bonds. This justifies a limited application of the modern electronic theories of the metallic state to problems involving these minerals.

Brillouin zones of the minerals in the iron-copper-sulfur system have been determined. The volume of these zones and the electron to atom ratios required to fill these zones have been calculated. These minerals exhibit the properties of semiconductors (negative Hall coefficient and increased conductivity with increased temperature), and therefore it is assumed that free electron states exactly fill one of the zones, with a small energy gap between the filled zone and the next higher zone. Use is made of a modification of the electron theory of H. Jones to explain why, as we go from compounds richer in iron and sulfur to compounds richer in copper, we form structures whose corresponding Brillouin zones, when filled, have lower electron to atom ratios.

INTERGLACIAL DEPOSITS AT ST. PIERRE, QUEBEC

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Near the village of St. Pierre les Becquets, P. Q., approximately 110 miles downstream from Montreal on the south shore of the St. Lawrence River, are exposed thick beds of interglacial peat in which are preserved wood and other plant material and some insects. The wood has a radio-carbon date of 11,050 ± 400 years, thus roughly equivalent to the Two Creeks interglacial stage.

A preliminary examination of plant material and pollen suggests a cold, moist climate and a fresh-water environment.

Although the areal extent of such deposits is not as yet fully known, it is conceivable that ice receded from the entire St. Lawrence valley and left it open to fluvial deposition and accumulation of peat at a time equivalent to the Cary-Mankato interval of Wisconsin. Whether the Great Lakes area was affected by drainage at this time remains a problem.

THERMODYNAMIC RELATIONS AMONG THE VANADIUM OXIDES, AND IMPLICATIONS OF THE COLORADO PLATEAU URANIUM-VANADIUM DEPOSITS

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Fields of stability of the low-valence vanadium oxides V_2O_2, V_2O_3 (VOOH), and V_2O_4 in water solution have been calculated as functions of pH and oxidation potential. The theoretical equilibrium relations indicate that V_2O_2 should not occur naturally; water would decompose, releasing hydrogen, before a sufficiently reducing environment could be attained. The field of V_2O_3 is essentially coexistent with that of $Fe(OH)_2$; V_3O_4 is stable down to approximately the same lower limits of oxidation potential as Fe_2O_3 [$Fe(OH)_3$]. The field of V_2O_3 also is essentially coexistent with the common metal sulfides over a wide range of total sulfur concentration. An implication from the theoretical relations is that the so-called black ores of the Colorado Plateau that contain low-valence uranium and vanadium compounds and metal sulfides (in addition to many other minerals) may be primary and the carnotite-roscoelite ores are derived from them by oxidation.

PRECAMBRIAN HISTORY OF THE CANADIAN SHIELD

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Detailed studies have shown that many folded belts within the Shield are no more complicated structurally than some Paleozoic and later mountain-built belts. Histories worked out in a number of these resemble one another and those of younger orogenic belts. That the similar historical sequences resulted from a succession of similar orogenic episodes and not from one or more Shield-wide foldings

is strongly indicated by the structural trends mapped, the prevalence of the sandstone facies in all the preserved strips of "Early Precambrian" sediments, the common occurrence of boulder conglomerates, and the extreme improbability of simultaneous folding of all parts of the Shield. The great length of time represented by the Precambrian indicates that many such epidoses occurred, each adding a strip to the continental platform.

Scarcity of granite debris in the oldest sediments of all the belts indicates that there was no original granite crust. Remnants of an original basic crust may still exist but would be very difficult to distinguish from superincumbent basic volcanics.

If these views are correct, most correlations made in the past, based on comparison of rock types and sequences of events, relate rock series and events that were not of the same age, but that represent similar stages in different orogenic cycles. Flat-lying sediments classed as "Late Precambrian" in one area may actually be older than deformed sediments and volcanics classed as "Early Precambrian" in another area.

EQUILIBRIUM THERMAL DECOMPOSITION OF DOLOMITE

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The experimentally determined P_{CO_2}-temperature stability curve of dolomite rises exponentially from approximately 400° C in air to approximately 640° C. at 65 atm. CO_2 pressure. The 400° value is in good agreement with the observed decomposition of dolomite under CO_2-free hydrothermal conditions.

The calcites formed by the decomposition contain Mg in solid solution. The similar occurrence of Mg in the calcites of numerous unweathered carbonate metamorphic rocks suggests that such solid solutions are stable under proper conditions of temperature, CO_2 pressure, and Mg^{++} activity.

This equilibrium curve has been further verified using magnesian calcite algal material, from which dolomite may be synthesized by solid-state reaction. Inasmuch as dolomite is formed from the algal material within the dolomite stability field and MgO by exsolution outside the field, the curve may be delineated particularly well by this technique.

CARBONIFEROUS GONIATITE ZONES OF ARKANSAS AND THEIR CORRELATION

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Pericyclus and *Munsteroceras* occur in an unnamed limestone beneath the Boone chert near Batesville, Arkansas. They are Kinderhook in age and resemble upper Tournaisian forms. No goniatites have been found in the Boone chert.

Crenistriate and finely striate *Goniatites* occur in the upper part of the Moorfield formation, representing roughly the P_1 or lower *Goniatites* zone (Upper Visean) of the British Carboniferous. Striate and coarsely striate *Goniatites*, together with *Neoglyphioceras*, *Lyrogoniatites*, and *Girtyoceras*, are found in the middle and upper parts of the Ruddell shale, the Batesville sandstone, and the basal part of the Fayetteville shale, representing approximately the P_2 or upper *Goniatites* zone (Upper Visean).

A *Cravenoceras*-like goniatite and a robust *Eumorphoceras*, both undescribed, characterize the middle and upper parts of the Fayetteville shale and represent the E_1 or lower *Eumorphoceras* zone (Lower Namurian) of the British section. Cephalopods are rare in the Pitkin limestone, but those found include *Cravenoceras richardsonianum* (Girty) and probably represent the E_2 or upper *Eumorphoceras* zone (Lower Namurian).

The *Homoceras* (H) and *Reticuloceras* (R) zones of the British section have not been recognized in Arkansas. The lower shales of the Pennsylvanian Morrow group have yielded a small *Cravenoceras*

like species in eastern Stone County. The *Gastrioceras* zone is well represented in the Prairie Grove limestone member of the Hale formation and the Brentwood limestone member of the Bloyd shale by several species of *Gastrioceras* and *Eoasianites* and *Pronorites arkansasensis* Smith. *Pseudoparalegoceras* appears in the Kessler limestone member of the Bloyd shale and is associated with *Paralegoceras* in marine tongues in the lower part of the Atoka formation.

TUNNEL GEOLOGY AT NIAGARA FALLS, ONTARIO

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Twin hydraulic tunnels, each 5½ miles long with a 51-foot bore and a 45-foot finished diameter are being driven under the City of Niagara Falls, Ontario.

These tunnels and an open canal, 2¼ miles long and 200 feet wide, will convey water from an intake above the Cascades to a powerhouse near Queenston. This enables 295 feet of the total 315 feet of head available to be utilized for the production of up to 1,200,000 horsepower of electrical energy.

The Clinton and the upper part of the Medina formation were chosen as the tunnelling horizon. The Irondequoit member, a dense massive limestone about 10 feet thick, provides an excellent roof. The thick overlying Rochester shale prevents the inflow of water from the porous strata of the Lockport. Seams in the Reynales and the soft shale of the Clinton cause some difficulty in controlling overbreak. Horizontal rock movement up to 2.5 inches has caused some heaving of the Grimsby in the invert.

Access to the tunnel horizon from the intake is at a 30-degree slope through the Lockport and Rochester formations.

The greatest depth below ground surface is 330 feet, and the tunnels rise following the dip of the formations until they emerge at a 30-degree slope to the open canal south of the buried St. David gorge.

ORDOVICIAN DUNDAS FORMATION AS EXPOSED IN THE EXCAVATIONS FOR THE TORONTO SUBWAY

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The Dundas formation, Ordovician, which forms the bedrock in the Toronto area, has been divided into four members, in ascending order: the Rosedale, the Danforth, the Humber, and the Credit. The present study is concerned with only the lower three members.

The lower 20 feet of the shale in the Don Valley Quarry, unexposed at the time of division into members, has a fauna similar to that of the section from 30 to 85 feet, named the Danforth member. The section from 20 to 30 feet, originally named the Rosedale member, appears to represent a faunal incursion, not all forms of which were persistent.

It was hoped that the subway excavation would permit localization of the Danforth-Humber contact. The excavated section, however, includes fauna formerly thought to be characteristic of each of these members. It is suggested that the contact is gradational and does not represent any sudden faunal incursion.

Since the division of the Dundas formation was based chiefly on faunal evidence, the various units would more properly be referred to as "zones". A complete revision of the nomenclature must await more detailed studies of the Humber and Credit members.

The strike of the beds in the Toronto area has been calculated as N. 78° W. with a dip of 27 feet to the mile S. 12° W.

Sedimentation and fossil accumulation in the section studied are indicative of relatively shallow water deposition under the influence of current action.

No glacial striae have been definitely identified on the bedrock surface.

PSEUDOMORPHOUS ILLITE AFTER BIOTITE

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Near Marysvale, Utah, hydrothermal alteration of the lowest unit of Bullion Canyon latite has produced unusually well formed illite pseudomorphs after biotite. A series is described which goes from biotite to illite with intermixed chlorite to a final almost pure illite. In the weathered zones a pseudomorphous series from biotite to mixed illite-chlorite and calcite is developed. Pseudomorphs range from 1 to 4 mm in diameter. Early exsolution of iron and late development of epidote occurs. Optical, stain, thermal, and x-ray data support the interpretation given. The paragenesis of hydrothermal clays in alkali-rich volcanic rocks is believed to be from mafic constituents to a mixture of chlorite and illite to illite. On crystal chemical grounds the extension of the sequence to pinite or sericite seems likely.

PETROGRAPHIC EXAMINATION OF WASHED, SCREENED AND CRUSHED SAMPLES OF COAL FROM THE SYDNEY AND ST. ROSE COAL FIELDS, NOVA SCOTIA*

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The coal seams of the Sydney coal field are in several ways extraordinary, since no great differences occur either in rank or petrographic composition. Over a stratigraphic interval of 3800 feet the volatile matter content ranges from 36 to 39 per cent (mineral matter free). All but one of the 12 seams may be classed as very bright coal containing between 73 and 84 per cent vitrain plus bright clarain. However, each seam contains dull coal horizons high in opaque matter and/or exinite. Concentration of these dull parts, by washing, screening, and crushing was the objective of this study.

Coals were examined from the Emery and Harbour seams of the Sydney coal field, and from No. 5 seam of the St. Rose field.

The petrographic analyses were carried out with an integrating stage, using polished specimens of ground coal, mounted in lucite. Accuracy tests on this method were highly satisfactory.

Results obtained are:

(1) Washed coal is lower in opaque matter than nonwashed coal, since opaque matter together with shaly impurities concentrates in the fractions of higher density.

(2) Concentration of opaque matter by screening alone depends on the amount and distribution of this material in the seam. Fusain is always higher in the fines fraction.

(3) A notable concentration of dull coal is obtained by pounding and subsequent screening. Grinding instead of pounding does not give results. Only by taking advantage of the natural differences in strength of the coal components can concentrations be obtained.

EXPERIMENTAL DEFORMATION OF HASMARK DOLOMITE

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Jacketed cylindrical specimens of anisotropic Hasmark dolomite have been deformed dry under a constant confining pressure of 5000 atm at a strain rate of 1 per cent per minute. Uniaxial compression and extension experiments were carried out on cylinders oriented parallel and perpendicular to the direction of the optic-axis maximum of the fabric, and for each orientation tests were conducted at

* Published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa, Canada

room temperature and at 300°C. All tests ended in fracture along a shear surface inclined at about 60° to the least principal stress axis, at a strain of less than 10 per cent. The stress-strain curves obtained suggest: (1) little or no strength anisotropy, (2) little or no effect of temperature on strength or ductility, (3) a marked dependence of strength on normal stress.

The grain orientation of the deformed specimens was investigated by standard U-stage methods. After deformation at 300°C the principal visible change in the fabric is a moderate development of $\{02\bar{2}1\}$ twins. Measurements indicate that most of these have a direction-sense of gliding as in calcite, thus conforming with the recent lattice analysis of Bradley *et al.* (1953). Change in crystal-axis orientation is shown only by the compression experiments and could reasonably be interpreted as a result of translation gliding on $\{0001\}$. Single-crystal experiments on dolomite by Johnsen (1902) support this conclusion. Further work by the authors, including predicted fabric changes, is in progress.

WESTERN TERMINATION OF THE UINTA FAULT IN DAGGETT COUNTY, UTAH

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A large high-angle thrust, long known as the Uinta fault, trends eastward along the north flank of the Uinta Mountains in northeastern Utah and northwestern Colorado. Some maps show a continuous fault extending from the vicinity of Hayden Peak in the western Uinta Mountains to the Vermillion Creek area of northwestern Colorado, a distance of about 120 miles (sometimes called "Crest fault"). Recent detailed mapping shows that at least two discontinuous faults exist. It is proposed that the name Uinta fault be restricted to that fault which parallels the eastern part of the range, first noted by Powell more than 75 years ago, and that the name Crest fault be applied to the more westerly fault in the higher part of the range.

At Clay Basin, Utah, where Precambrian Red Creek quartzite is in contact with Late Cretaceous Hilliard shale, the stratigraphic throw of the Uinta fault probably exceeds 20,000 feet; about 30 miles west, at Palisade Park in Sheep Creek Canyon, the throw diminishes to zero, and the fault terminates in a sharp overturned monoclinal fold.

The authors have done no detailed work on the Crest fault. A thrust fault that may mark its eastern end is exposed in the first large ravine tributary to Sheep Creek northeast of Palisade Park. This fault, which there overlaps and is parallel to the Uinta fault for a distance of about 4000 feet, does not join the Uinta fault at the surface, although it may do so at depth.

SUMMARY OF THE IMPLICATIONS OF THE GEOMETRY OF GEOSYNCLINES

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A four-stage orthogeosynclinal cycle having the following dimensions is postulated.

Stage 1. Incipient geosyncline with crustal layering of: sialic material 10 km; simatic material 25 km; ultra-simatic material below.

Stage 2. Full trough defined as the filled basement flexure, an imaginary standard geosyncline 193 km wide and 18 km deep.

Stage 3. Primary compression with a lateral shortening of 25 per cent.

Stage 4. Isostatic uplift and contemporaneous erosion ending with a stable shield and crustal layering of: siliac material 20 km; simatic material 15 km.

Through use of background data and analytical sections for each trough-forming mechanism these unquestionably qualified implications were developed: (1) The basement flexures of orthogeosynclines approximate flat arcs. (2) Trough formation will not produce Appalachian structures. (3) The Sierra Nevada evidences shortening of the whole crust, while in the Alps shortening was con-

fined to the sial. (4) Primary compression produces a shearing strain in the sedimentary fill. This strain is: (a) maximum under slight near-surface loads; free release produces imbricate structure; (b) less under loads of intermediate depth and lateral position; this produces tectonites and sheared foliates; (c) negligible under greatest load and axial position; this permits production of massive rocks. (5) No geometric difficulty is presented if primary compression takes place beneath an ocean trench. (6) Secondary compression in the orogenic root develops during isostatic uplift between fixed massifs. The resultant downward force accounts for stabilization during peneplaination. Multiple erosion surfaces mark loss and regain of balance.

RELATION BETWEEN FRACTURE PATTERN AND HYPOGENE ZONING IN THE FREELAND-LAMARTINE DISTRICT, CLEAR CREEK COUNTY, COLORADO

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Hydrothermal veins of Tertiary age in the Freeland-Lamartine district, Clear Creek County, Colorado, fill long, cyma-shaped fissures that cut complexly folded Precambrian metasedimentary and granitic rocks. The fissures formed under a regional sheer stress that created a fracture pattern composed of three elements which can be dated in a distinct sequence. Mineralization took place in two stages during the period of fracturing; the veins were deposited in open space and show well-defined zoning—individual veins have a central segment of pyrite-gold ore bounded at both extremities by galena-sphalerite ore.

The first set of fractures developed approximately parallel to north-northeast-trending axial planes of major Precambrian folds; these fractures now form the middle segment of the cymoid fissures. Subsequent fractures formed at both ends of the early fractures, one set with east-northeast trends and the final set with east trends. The later fractures cut through and locally offset the earlier fractures.

In the first stage of mineralization quartz and auriferous pyrite with some chalcopyrite and tetrahedrite filled the early fractures, chiefly the north-northeast set and adjacent parts of the east-northeast set. In the second stage galena and sphalerite with minor amounts of quartz, pyrite, chalcopyrite, tetrahedrite, and carbonates filled the younger fractures near the ends of the cymoids. Veins formed during the second stage of mineralization locally cut the earlier veins in the east-northeast-trending segments of the fissures, forming composite veins.

ELECTROMAGNETIC SURVEYING OF DRILL HOLES FOR THE DETECTION OF CONDUCTING SULFIDES

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A diamond drill hole will sample only the diameter of the hole, and many ore bodies present can be missed readily. In a manner analagous to surface electro-magnetic surveying the region up to a radius of about 400 feet about the hole can be surveyed for conducting sulfides by use of special apparatus. The direction in which these sulfides lie as well as some indication of their size can be inferred from the results. The method of testing vertical drill holes is described showing how it is possible to allow for the departure of the hole from the vertical. Testing of angle holes is outlined although field tests have not been made with this method.

Results of field tests in the Sudbury basin in drill holes passing through barren areas and in holes collared in areas of known sulfides are discussed.

The method is useful in reducing the number of drill holes required to explore an area and in indicating the direction in which further drilling should be done.

SIGNIFICANCE OF STYLOLITES IN SANDSTONES

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Stylolites are much more common in sandstones than has been previously realized. In the Appalachian area stylolites occur in nearly every quartzose or calcareous sandstone. Most of the stylolite seams are parallel to bedding, but some have formed along fractures at an angle to bedding. The seams parallel to bedding are as well developed in the subsurface as they are at the outcrop. Along the seams interpenetrations occur not only between quartz grains but also between quartz and calcite, feldspar, biotite, or muscovite. The stylolites are clearly the result of pressure solution.

Permeability across the bedding was reduced where residual argillaceous material accumulated along the seams. Stylolites may have an important effect on the competency of a formation inasmuch as the interlocking stylolite columns tend to impede differential movement between beds. An indication of the effect of stress on the solubility of different minerals can be obtained where seams occur in impure sandstones. Most of the stylolitic solution took place before folding, but some solution continued after folding. The silica which went into solution along the seams may be the source of much of the cement in the sandstones. However, there is no simple relationship between the amount of stylolitic solution and the amount of cement.

PRE-BELTIAN GEOLOGIC HISTORY OF MONTANA

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The sequence of petrologic units in the pre-Beltian of southwestern Montana is: (1) The oldest units underlie the Cherry Creek Group and include rocks of the Pony Group as well as other pre-Cherry Creek rocks which probably are not time equivalents of the Pony. Main types present are biotite-garnet gneiss, granite gneiss, injection gneiss, and amphibole gneiss. (2) The Cherry Creek Group consists of metasediments including marble, quartzite, micaceous schists, sillimanite schist, banded ironstones with intercalated layers of amphibole gneiss, and amphibolite representing metamorphosed mafic sills and flows. (3) A number of post-Cherry Creek intrusives, all of which show varying degrees of metamorphism, include, among others, the Dillon granite gneiss, widespread in Beaverhead and Madison counties, the granite of the Jardine district, and the Pinto metadiorite in the Little Belt Mountains. (4) Widely distributed bodies of unmetamorphosed periodotite and associated ultramafic rocks have as their largest representative the Stillwater Complex. (5) Post-Stillwater intrusives are represented mainly by the granite of the Beartooth Range. (6) Numerous and widespread diabase dikes that cut all these older units do not extend into Beltian rocks. Considerable new information on the pre-Beltian complex has been obtained from a study of xenoliths which are relatively common in Tertiary intrusive rocks, for example, such as those of the Bearpaw Mountains and the Sweetgrass Hills.

ORIGIN OF PROBLEMATIC FOSSILS IN THE MORROW GROUP AND IN ADJACENT BEDS OF MISSISSIPPIAN AND PENNSYLVANIAN AGE IN ARKANSAS

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The Fayetteville shale, Mississippian; Hale formation, Early Pennsylvanian; and Atoka formation, early Middle Pennsylvanian, in northern Arkansas contain a variety of surface marks, impressions, and structures variously attributed to organic or inorganic origins. Several of these represent

the work or impressions of organisms. Certain kinds are restricted to particular facies and have limited, local use as guide fossils.

Chief among these are (1) the borings of marine organisms (pelecypods?) in boulders in a basal conglomerate bed of the Hale formation; (2) circular "rill marks" in the Cane Hill member of the Hale formation; (3) *Arthrophycus*-like structures in the Cane Hill and Prairie Grove members of the Hale formation which prove to be the source of the peculiar, honeycomb structure of the Prairie Grove limestone and to represent the burrows of a sedentary or temporarily sedentary animal; and (4) *Taonurus colletti* (?) Lesquereux and species of *Scalarituba*, both of which are abundant in and characteristic of a facies in cyclothems in the Atoka formation. Evidence suggests plant rather than animal-burrow origin for this species of *Taonurus*.

SPECTROGRAPHIC CORRELATION OF METABENTONITES IN TEXAS CRETACEOUS BEDS

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Detailed field and spectrographic measurements of metabentonite beds were made in limited sections of the Cretaceous Austin and Eagle Ford groups of the Dallas, Texas, area. Metabentonites are formed by the devitrification of thin beds of volcanic ash which have fallen to the sea floor. They are usually distributed over wide areas. Because of this unique origin, such beds would serve to define excellent time-rock units once correlation has been established. Spectrographic analysis was used to evaluate the Ca-Mg and Si-Al ratios for various bentonite beds, and these ratios were considered indices for each bed. Using a spectrographic precision limit of $\pm$ 20% relative deviation, the possibility of correlation between beds only a few inches thick, over a lateral distance of 5 miles, was investigated. This local test of correlation is important, because it implies the possibility of extending the work over greater distances, thereby establishing accurate time-rock marker beds in the Eagle Ford and Austin groups.

PETROGENESIS OF THE GLASTONBURY GRANITE GNEISS, CONNECTICUT*

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The Glastonbury granite gneiss, an elongate body over 40 miles long in central Connecticut and Massachusetts, reaches its greatest width, just under 5 miles, near Glastonbury, Connecticut. This report is based upon a study of the Glastonbury quadrangle.

The gneiss forms an elliptical dome in a probable anticlinorium of Bolton schist. Both the dome and the anticlinorium are overturned to the east. The Bolton schist is a biotite-muscovite-quartz oligoclase schist that includes quartzite, marble, lime-silicate rocks, and staurolite and garnet schists.

Four gradational facies of Glastonbury granite gneiss have been recognized. From west to east they are: (1) schistose gneiss, (2) porphyroblastic gneiss with abundant mafic schlieren, (3) flaser gneiss, and (4) felsic gneiss. The schistose gneiss, at the western contact, may represent a metasomatic transition facies. In the porphyroblastic gneiss potassium metasomatism reaches a maximum with development of coarse potassium feldspar porphyroblasts. In this facies, abundant mafic schlieren rich in biotite and epidote show discordant contacts but strong parallel foliation with the enclosing gneiss. A secondary weak foliation, visible in thin section, is nearly parallel to the contact between the schlieren and the gneiss. The flaser gneiss has coarse quartz flaser suggestive of quartz

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pebble palimpsests. The highly felsic gneiss appears on the eastern contact, vis-à-vis quartzites in the Bolton schist.

The data suggest that the Glastonbury granite gneiss was formed by granitic solutions through potassium-silicon metasomatism. This process preserved many features of the original country rock, and the addition of material may be responsible for the doming of the formation.

KYANITE, ANDALUSITE, AND SILLIMANITE IN THE SCHISTS IN BOEHL'S BUTTE QUADRANGLE, IDAHO

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Kyanite, andalusite, and sillimanite are found together in the cordierite-bearing mica schists of the Prichard formation of the Precambrian Belt series exposed in the Boehl's Butte quadrangle in the southern part of the Idaho "panhandle". Microscopic studies of these schists suggest that the following inversions took place: (1) sillimanite → kyanite, (2) kyanite → andalusite, (3) kyanite → sillimanite, (4) andalusite → sillimanite. These inversions are probably related to the fluctuation of temperature and stresses during the complex regional and thermal metamorphism to which the schists were subjected. In some thin sections all three minerals occur side by side, suggesting that they may have crystallized under physical-chemical conditions in which all three can exist in equilibrium. The association epidote-plagioclase (An_{28}) in the calcium-rich beds of the same area suggests that the temperature during the crystallization was close to 400°C.

STUDIES OF RADIOACTIVE COMPOUNDS: VII-PHOSPHURANYLITE AND DEWINDTITE

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Phosphuranylite from Urgeirica, Portugal, with refractive indices α 1.669, β 1.710 (Na) shows only a trace of lead spectrographically. Rotation and Weissenberg films gave the data: Orthohrombic Bmmb; $a = 15.85$, $b = 17.42$, $c = 13.76$A.

Dewindtite from Kasolo gave a practically identical powder pattern confirming Frondel's (1950) statement that the two minerals are isostructural. The indexed powder pattern of dewindtite gave the cell constants: $a = 16.00$, $b = 17.62$, $c = 13.66$A. Schoep's analysis and measured density (5.03) are in better agreement with the formula $Pb_3(UO_2)_8(PO_4)_4(OH)_8 \cdot 9H_2O$ (calc. G. 4.95; Z = 4) than the hitherto accepted formula $Pb_3(UO_2)_8(PO_4)_4(OH)_4 \cdot 10H_2O$ (calc. G. 4.46; Z = 4).

The analyses of phosphuranylite by Frondel (1950) do not lead to rational cell contents. The formula $Ca_3(UO_2)_8(PO_4)_4(OH)_8 \cdot 9H_2O$ (calc. G. 4.14; Z = 4) is proposed by analogy with dewindtite.

RECRYSTALLIZATION OF METAMICT ZIRCON

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The recrystallization of metamict zircons has been studied by observing the heat emission and changes in the density and structure during annealing. It has been found that: (1) the heat energy liberated during recrystallization is proportional to the degree of structure damage, (2) the effect of heat treatment at constant temperature on the density of metamict zircons cannot be explained in terms of a single-stage reaction, and (3) during annealing the unit-cell dimensions approach those of undamaged zircon more rapidly than the density approaches that of undamaged zircon.

DEPOSITION OF HIGH-TEMPERATURE, NONMAGMATIC MAGNETITE

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Reduction of contamination and analytical errors corrects previous values of magnetite solubility, from equilibration in Morey bombs. In pure water at 180°–510° and 490–1280 bars, solubility is less than 0.03 ppm iron, the sensitivity of colorimetric analysis of the solution. The large quantity of water necessary to form known "hydrothermal" deposits with such small solubilities indicates that the magnetite was not precipitated from neutral solutions. A few experiments suggest a similar low limit of solubility in alkaline solutions.

Magnetite is appreciably soluble at 25° in dilute HCl solutions. With magnetite in a platinum-lined bomb at 390° and 425 bars, we found less than 0.03 ppm iron in solution at 10^{-6} N HCl, but more than 5 ppm at 10^{-4} N. The latter is considerably greater than the volatility of ferric chloride, in the presence of a large porportion of water, as extrapolated from Shafer's data, suggesting solvent action by water. This transition from water solubility to halide gas mixtures is now being investigated.

These data indicate possible deposition of iron oxides when a halide-rich fluid enters a region of higher water content. Coupled with the recent proof by Vinogradov of deposition when halides contact calcite, it emphasizes the importance of deposition by change of composition rather than temperature or pressure.

STRATIGRAPHIC SIGNIFICANCE OF QUATERNARY WEATHERING PHENOMENA IN A LAVA PLATEAU ON SEWARD PENINSULA, ALASKA

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Quaternary andesite pahoehoe flows of the Imuruk lava plateau are subdivided and correlated with a local glacial chronology on the basis of differences in surface weathering and stratigraphic interrelationships.

The following units are recognized: (1) a young flow essentially undisturbed by frost-riving; (2) an older flow frost-rived to depths of 5 to 10 feet but still bearing well-preserved initial microrelief; (3) still older flows reduced by frost-riving to undulating rubble fields in which initial microrelief is nearly obliterated; (4) thoroughly frost-brecciated flows mantled by 5 to 20 feet of wind-blown silt; (5) underlying flows whose upper portions are friable and intimately permeated by limonite, indicating weathering in a climate much warmer than that to which later flows were subjected.

Frost-riving is not active today on the well-drained rocky or rubbly surface of the younger flows. Shorter summers or more snowfall would favor more extensive frost-riving in the Imuruk lava plateau and glaciation in near-by mountains. Therefore, the youngest, nonrived flow (1) is post-glacial, the slightly frost-rived flow (2) is contemporaneous with or older than the last Seward Peninsula glaciation, and the more thoroughly brecciated flows (3) are contemporaneous with or older than the next older glaciation. The silt-mantled flows (4) are contemporaneous with a still-older glaciation during which active outwash plains were present near by. The oldest, deeply weathered flows are contemporaneous with or older than a very warm, early interglacial interval represented in near-by areas by peat containing fossils of warm-climate trees and interbedded with glacial and periglacial gravel.

EVIDENCE OF A VERY WARM PLEISTOCENE INTERGLACIAL INTERVAL ON SEWARD PENINSULA, ALASKA

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Organic deposits along the Pilgrim River interbedded with deposits of the two older of four recognized glaciations on Seward Peninsula and organic deposits along the Kuzitrin River interbedded

with early Quaternary periglacial gravel contain a fossil flora similar to the present coastal forest of Southeastern Alaska. Identified material includes wood of Douglas fir, spruce, and cedar (*Thuja*), and pollen of pine, fir, hemlock, two species of spruce, and birch.

Periglacial gravel above the organic deposits contains wood that is possibly spruce but more likely is larch and fragments and twigs of poplar—indicators of forest like that of present interior Alaska rather than the tundra now covering central Seward Peninsula.

Late Quaternary interglacial or interstadial muck of central Seward Peninsula also contains a flora characteristic of the interior boreal forest, whereas periglacial sediments tentatively correlated with the later glaciations have yielded only plant remains consistent with the present tundra vegetation.

The relationships suggest that early Quaternary interglacial intervals in northwest Alaska were characterized by climates much warmer and more humid than the present climate; early glacial climates evidently had longer, warmer summers, and therefore must have had much heavier winter precipitation to support glaciation.

Evidences of early Pleistocene climates, and marked contrasts of these with present climate and vegetation, have not been reported for other parts of Alaska. Future investigations of Quaternary stratigraphy in central and northern Alaska should give special attention to the search for additional Quaternary floras.

GRANULITES, AMPHIBOLITES, MYLONITES, AND ASSOCIATED ROCKS OF THE CUCAMONGA CANYON AREA, SOUTHEASTERN SAN GABRIEL MOUNTAINS, CALIFORNIA

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The oldest rocks of the Cucamonga Canyon area, California, are granulites that have been folded in an apparently homoclinal sequence, striking N. and dipping almost vertically. The granulites, comprising mineral associations characteristic of the granulite facies, are probably sedimentary and volcanic rocks that have been dynamothermally metamorphosed.

The granulites have been altered to amphibolites and mylonites along N.-NW.-dipping thrust planes. In Aurela Ridge belt, the granulite structures remain almost intact, and only minor amounts of polymetamorphic rocks are present. South of Aurela Ridge belt, E.-NE.-trending structures prevail, yet relic granulite structures and minerals are recognizable. In a belt hundreds of feet wide north of Aurela Ridge belt, the mylonites and amphibolites strike E.-NE., and granulite structures are obliterated, although relic granulite minerals are plentiful. Farther north, E.-NE.-trending mylonites and minor amphibolites occur in Sarac Ridge belt half a mile wide; traces of granulite minerals present suggest these rocks may have been derived from the granulites.

The amphibolites and mylonites are syngenetic. While the felsic granulites were being deformed cataclastically to form mylonites, the mafic granulites were deformed through neomineralization to form amphibolites. Mineral associations indicate that these polymetamorphic rocks were probably formed by the metamorphism of the granulites under the amphibolite facies conditions complemented by intense shearing stress.

Gneissose quartz diorite north of Sarac Ridge, probably emplaced synkinematically, may represent mobilized "quartz-dioritized" granulites. Small quartz monzonite intrusives in the quartz diorite pluton, emplaced post-kinematically, may have promoted recrystallization of the mylonites.

PETROLOGY OF A GABBRO-GRANOPHYRE COMPLEX IN THE WICHITA MOUNTAINS, OKLAHOMA

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A gabbro-granophyre complex of Precambrian age is exposed in the eastern and central Wichita Mountains in southwestern Oklahoma. The complex probably forms horizontal sheetlike intrusions.

The gabbroic rocks are interpreted as formed by gravitational differentiation as some outcrops show a downward gradation from an anorthosite through an olivine gabbro to a troctolite. Two structures are found in the rocks: (1) banded structure is due to magmatic flow; (2) rhythmic layering appears to be related to crystal settling. The basic magma had a temperature somewhat above 1100°C. at the time of intrusion as evidenced by the occurrence of diopsidic lamellae (En_{75}) in hypersthene (Fs_{29}). Mineral compositions reveal simultaneous soda enrichment in plagioclase and iron enrichment in coexisting pyroxenes and olivines. A discussion of petrographic features indicative of assimilation of argillaceous and quartzitic sediments is included.

Between the gabbro and granophyre a narrow zone of "intermediate rock" (leucogranogabbro, granogabbro, syenogabbro, and granodiorite) exhibits peculiar mineralogical and textural characters. Field occurrences and petrographic studies indicate that these rocks originated as alteration products of the gabbroic rocks through contact action of a granophyric melt. As a result of the contact action, the gabbroic rocks through contact action of a granophyric melt. As a result of the contact action, geochemical accumulations of TiO_2, FeO, and P_2O_5 occur in the "intermediate zone." The occurrence of leucogranogabbro is the first recorded example of the rock formulated by Johannsen in 1932.

Criteria of a replacement origin of granophyre are inconclusive. Available data support a magmatic origin. The granitic magma may have developed through fractional crystallization at depth. The resulting granophyric texture is unrelated to eutectic crystallization.

"MAYES" PROBLEM OF THE MISSISSIPPIAN IN NORTHEASTERN OKLAHOMA

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Strata between the cherty Boone and Fayetteville shales, previously called Mayes formaion, can be divided into five lithic zones. In ascending order these are (a) lower glauconitic limestone, (b) blue-gray, argillaceous limestone, (c) chert-pebble bearing calcarenite, (d) yellow-blue, calcareous siltstone and shale, and (e) upper, gray, oölitic limestone.

The lower glauconitic facies is gray, medium-crystalline, partly oölitic, phosphatic, crinoidal, and locally cherty. It rests unconformably on Keokuk near Tahlequah, on Short Creek in sec. 2, T. 15 N., R. 23 E., and on Reeds Spring near Marble City. It grades southwestward into black, crinoidal, cherty, argillaceous limestone near Cookson and Blackgum. *Syringothyris textus*, *Orthotetes keokuk*, *Nudirostra carboniferum*, and *Moorefieldella eurekensis* are characteristic. It is correlated with the glauconitic Warsaw of Ottawa County.

Succeeding units (b, c, d) are lithologically and faunally similar with *Nudirostra carboniferum*, *Moorefieldella eurekensis*, *Spirifer arkansanus*, *Griffithides pustulosus*, and other typical Moorefield forms. Uppermost shaly beds resemble the Ruddell of Arkansas. It is believed that the term Moorefield formation should be applied to these units and that lithic subdivisions should be given member rank.

Upper "Mayes" (e) is gray, medium crystalline, and oölitic with *Agassizocrinus*, *Diaphragmus cestriensis*, *Spirifer leidyi*, *Paladin mucronatus*, and other species common to the Hindsville limestone of Arkansas. It lies with disconformity on upper Moorefield in Mayes County; on eroded remnants of Moorefield or Boone in Cherokee and Adair counties; and overlaps the Moorefield northward in Ottawa County. It thins southwestward to extinction near Braggs Mountain (T. 15 N., R. 20 E.).

The Hindsville, Fayetteville, and Pitkin constitute a conformable sequence of Chester age.

DEMONSTRATION POLARISCOPE

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The demonstration polariscope is constructed of two crossed Polaroids 4 inches apart and 4 inches square. An ordinary 60-watt lamp beneath the lower Polaroid serves as a light source. Above the lower polarizer is a stage on which cleavage fragments or mineral slices may be placed and rotated

to demonstrate extinction angles, twinning, interference figures, and other phenomena observed in plane-polarized light. By inserting polished spheres of crystals between the Polaroids one can observe interference figures as described by Professor Horace Winchell in 1947.

This polariscope has the additional advantage of permitting demonstration of interference figures produced by thin slices of minerals. A 3-inch plastic sphere can be slid into position between the polarizers; and, if a suitably oriented slice is placed on the stage, an interference figure is observed to fill the sphere. A mirror placed over the upper Polaroid at 45° enables one to demonstrate interference figures to a class of 20 or more at one time.

PETROLOGY OF ENCHANTED ROCK PLUTON, LLANO AND GILLESPIE COUNTIES, TEXAS

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The Precambrian pluton consists of four concentric zones: (1) outer zone, medium to coarse leucogranite and granite; (2) intermediate zone, medium to coarse granite and quartz monzonite; (3) intermediate central zone, coarse quartz monzonite and alkalic granodiorite; and (4) the core, fine to medium leuco-quartz monzonite and leucogranite. Seriate porphyritic texture prevails. Rapakivi texture is most abundant in zone (3).

The magma was probably uniform prior to emplacement, and concentric zones were developed during emplacement. Crystallization-differentiation accompanied by filter-pressing of a crystal mesh in which microcline separated as the first stable crystalline phase are responsible for rock types and their distribution. The finer grain of the core is believed due to partial escape of volatiles and loss of heat, the latter due mainly to depletion of the magma reservoir.

Microcline phenocrysts, despite size, maintain a mean length-width ratio of 2:1 throughout all rock zones. Standard deviation of mean length for zones (1), (2) and (4) is relatively low and for zone (3) is large. Values for the latter zone are probably due to a longer time of crystallization, presence of a portion of the filter-pressed plagioclase fraction and small-scale feldspathization.

Forces that produced steep regional folds may have been sufficient to draw the magma into the chamber. Arcuation of schlieren in zone (1) suggests the magma rose with a spiral motion.

OUTBURSTS IN COAL MINES

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This paper is confined to the treatment of occurrences of varying degrees of suddenness, encountered normally only in coal mines, when relief of stress is accompanied by an outflow of gas contained mainly in the coal.

The "outburst" phenomenon is defined in relation to other forms of relief of stress, and the two factors that appear to be dominant in these occurrences—change of stress equilibrium and of the association of gas with the coal—are discussed.

These occurrences are of particular interest to the geologist: in the classical development they have always been associated with areas of pronounced structure. Examples from several countries are briefly given.

The present state of knowledge of this problem is reviewed indicating that, while practical precautionary methods in the mine have reduced hazards to human life, a clear conception of the causes

of these occurrences has not yet been established, principally on account of the inconclusive evidence as to the state of association of gas and coal.

The studies, underground, of stress considerations and the laboratory work on the coal-gas association, inaugurated by the Canada Department of Mines & Technical Surveys, are described in the form of a preliminary progress report.

POPULATION STUDIES IN *STROPHODONTA* FROM THE MICHIGAN DEVONIAN

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The lower six units of the Devonian Traverse group, exposed in the vicinity of Alpena, Michigan, are (in ascending order) the Bell, Rockport Quarry, Ferron Point, Genshaw, Newton Creek, and Alpena formations. These limestones and shales, totalling about 380 feet, yield collections of the brachiopod *Strophodonta* so abundant that meaningful observations on taxonomic diversity and population density can be made.

Unusually abundant and stratigraphically complete collections from the lower four formations involve continuous variation between extreme morphologic types. Subspecies are employed to delineate morphologically overlapping groups which are statistically and stratigraphically separable. Alpena *Strophodonta* have been assigned to eight species. Although the samples are small, the low variability and absence of morphologic overlap render these groups quite distinct. Alpena populations thus stand in contrast to those of underlying formations which have large samples and few species.

Accepting the number of collectable fossils as an approximate index of the original population density, it is concluded that during pre-Alpena deposition two or three contemporaneous species formed large and variable populations; and that Alpena deposition was marked by small, morphologically distinct populations involving eight species. The Alpena limestone is also remarkable for biohermal masses apparently representing ancient reefs. The coincidence of reefy lithology with maximum taxonomic diversity suggests a causal relationship. Furthermore, it is probable that an environment characterized by local reefs would have provided ideal conditions for speciation by isolating portions of large, variable, and widespread populations.

TIME FACTOR IN GEOLOGICAL PROBLEMS

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The time dependence of physical phenomena is discussed with particular reference to events which have a geological significance.

In examining the significance of radioactivity in geophysical problems, most investigators have assumed (for simplicity) a constant rate of heat generation—although its decrease during the Earth's life time is approximately 50 per cent. A detailed study of the thermal *history* of the Earth is being carried out, with particular regard for this time factor. A graph has been obtained of the total surface heat flow as a function of time. This graph depends on the age of the Earth, although its broad features are independent of this factor. A particular feature of the graph is the rather sudden slowing up of the decrease in the heat flow about 1500 million years after the Earth was born. With our present estimate of the age of the Earth (3500 million years), this occurred about 2000 million years ago. The oldest rocks (of a greenstone facies) in at least three continents (North America, Western Australia, and South Africa) have been dated as at least 2000 million years, and there is evidence that they are of the same peculiar petrological type. It is suggested that these greenstone volcanic areas represent the original nuclei of the continents and are the remains of the tectonic disturbances of this early phase in the Earth's history.

DISTRIBUTION OF RARE ELEMENTS WITHIN GRANITES AND GRANITIC PEGMATITES

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The distribution and mode of occurrence of rare elements in a given igneous rock are governed by several well-known factors, chiefly: (1) composition of the magma, including concentrations of the rare-element ions; (2) pressure-temperature conditions during crystallization of the magma; and (3) size, charge, polarizability, and other properties of the rare-element ions.

During crystallization of a magma under a given set of conditions, a rare-element ion may enter the structure of a common mineral (Ga in feldspar) or a rarer mineral (Cs in beryl); it may enter, or be trapped by, a much less appropriate mineral structure (Sn in muscovite), followed in some instances by transfer to an exsolved mineral; it may be concentrated in the residual fluid until it forms a mineral of its own (Cs in pollucite); or it may remain dispersed in the residual fluid until ultimately it is bound to the surface of the nearest crystal lattice.

The first three mechanisms seem to account satisfactorily for the distribution of Be, Cs, Rb, Tl, Li, Nb, Ta, the rare earths, Sn, Ti, W, Mo, U, Th, and other rare elements in granitic pegmatites and some granites. The fourth mechanism evidently becomes prominent during crystallization of other granitic rocks, especially those formed from magmas of relatively high viscosity. It results in end-stage attachment of numerous rare-element ions to the crystal surfaces of common silicate minerals. The binding is relatively weak, and these ions are readily mobilized if the host granites are altered or weathered. Despite their low concentrations, enormous quantities of rare elements might thus be leached from a single large body of granitic rock.

ZONES OF REGIONAL METAMORPHISM IN THE PRECAMBRIAN OF NORTHERN MICHIGAN

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Precambrian rocks are exposed throughout an area of about 7500 square miles in northern Michigan. Of this area, approximately 3300 square miles is underlain by unmetamorphosed upper Precambrian (Keweenawan), about 2700 square miles by metamorphosed middle Precambrian (Huronian), and about 1500 square miles by metamorphosed lower Precambrian ("Archean"). Flat-lying or low-dipping strata of Paleozoic age overlap the Precambrian along the east margin of the area.

The degree of metamorphism is most clearly shown by mineralogic changes in the middle Precambrian sedimentary rocks, especially the iron formations and the graywackes and slates, and in the late middle Precambrian basic intrusive rocks. These rocks were metamorphosed during the Killarney interval of orogeny and minor granite intrusions. At least one earlier period of major metamorphism (Algoman) is recognized, and in near-by areas of Wisconsin and Minnesota later, but areally more restricted, metamorphism is related to the intrusion of the upper Precambrian Duluth gabbro and equivalent masses.

Zones of metamorphic intensity delineated by sillimanite, staurolite, garnet, biotite, and chlorite isograds or their equivalents are completely or partly developed around four nodes, two of which lie in immediately adjacent parts of Wisconsin. The zones range in width from less than a mile to about 30 miles, with metamorphism of low grade being areally dominant over that of intermediate or high grade. Retrograde metamorphism, not accompanied by shearing, is widespread.

Granite dikes and small stocks are fairly common in the areas of higher-grade metamorphism.

Though doubtless both the metamorphism and the granite intrusions were part of the same orogenic cycle, the granite exposed in most areas is clearly later than the regional metamorphism.

GEOLOGY OF CAMPBELL RED LAKE MINES LIMITED

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Rock types in the mine area are andesite, Campbell diorite, rhyolite, syenite porphyry dikes, and three zones of altered rock.

Different phases of the altered zones have been mapped as a single unit.

The various beds all strike slightly north of west and dip south.

The northernmost altered zone traces out an S-shaped fold which moves southwest at depth. Associated west-raking ore bodies are of two kinds:

(1) Quartz carbonate veins occupy shears which strike northwest, dip vertical or steeply south, and trend parallel to the fold axes.

(2) Irregular ore bodies trend in a northerly direction and occupy tension breaks believed consequent to increased acuteness of folding at depth.

Most of the south zone ore occupies a compound shear which strikes northwest and dips vertical to steeply south. At the west end, the ore terminates at the south, folded contact of the central altered zone where the contact strikes southwest and dips northwest.

The east end of another vein with northwest strike and vertical dip terminates at a similarly folded bed of Campbell diorite.

The folding was formerly interpreted as faulting, but beds on strike with the proposed fault are uninterrupted.

Replacement bodies located north of the south zone shear rake west and cross the shear at depth.

Ore moves north on the east side of a "black line" fault.

Minor folds indicate that the mine is located on the south limb of a major fold which pitches steeply southwest.

COPPERMINE RIVER AREA, NORTHWEST TERRITORIES, CANADA

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Exploration for copper in a region of 7000 square miles south of the Arctic Ocean between west longitudes 114° and 118° has covered a period of nearly 200 years. Early efforts were confined largely to general exploration and a description of the country. Intensive prospecting of this area was undertaken by two companies in the period 1929–1931. Since 1943 information gained by further prospecting, geologic mapping, and diamond drilling has added to our knowledge of the area.

In the Coppermine, late Precambrian sediments and volcanics rest unconformably on a basal granite. The younger rocks are separated by a disconformity into an older series of sediments—predominantly dolomites—and an overlying section of basalt and diabase flows with interbedded sandstones, shales, and slates.

The area covers the southwestern portion of a large, shallow basin more than 400 miles in diameter. Northeast-trending major tension faults have been traced for more than 50 miles, and the zone of this faulting has been traced to Great Bear Lake, 100 miles to the southwest. Copper mineralization, principally primary chalcocite and bornite, is widespread in the outcrop area of the basalts of the lower Coppermine Series and is closely associated with the faults. Although no mineable ore deposits have been found, the total volume of copper in numerous showings throughout this region marks the Coppermine as an important area of copper mineralization.

PARAGENSIS OF THE ORES OF THE PALOMAS (HERMOSA) DISTRICT, SOUTHWESTERN NEW MEXICO*

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Low-temperature lead-zinc-silver mineralization of Tertiary age characterizes the Palomas Mining District in the western part of Sierra County, in southwestern New Mexico. The ore occurs in fissure veins and replacement bodies in limestones and dolomitic limestones of Paleozoic age. Structural control of ore deposition has been exerted by fractures and by shaly horizons in the Country rock. The principal hypogene minerals are galena, sphalerite, chalcopyrite, and argentite. Associated minerals are pyrite, polybasite, and tetrahedrite. The gangue consists mainly of talc, with associated calcite, quartz, barite, and clay minerals. Supergene minerals include covellite; native silver; limonite; lead, zinc, and copper carbonates; silver halides; and more rarely such minerals as vanadinite, descloizite, and pyromorphite.

Talc, which occurs both as vein filling and in zones of wall-rock alteration, is thought to have been formed by the action of the silica-bearing hypogene solutions. Little transportation appears to have taken place during the early stages of oxidation, as evidenced by the intimate association of hypogene and supergene silver minerals. The mineralization is believed to have been brought about by alkaline hydrothermal solutions whose origin is in doubt, but may be connected with the sources of tertiary volcanic activity in the area. An unusual feature of the deposits is the occurrence of talc as the chief gangue mineral.

ARCHAEOLITHOTHAMNION—ITS FOSSIL AND MODERN REPRESENTATIVES

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Archaeolithothamnion is the oldest and structurally the most primitive genus of coralline algae. Its fossil record extends from the Middle Cretaceous to the present. During the Cretaceous it was represented by a great variety of forms some of which apparently were ancestral to other genera especially *Lithothamnion* and *Lithophyllum*. The genus reached its zenith during the Eocene and has slowly declined ever since. Today it is represented by about 15 species all living in tropical or subtropical marine waters.

The anatomical structures are discussed in detail.

An outline is presented of the known geological history of the genus. Its importance as a forerunner of most if not all, modern genera of articulated corallines is discussed. Tables give the basic data on the species known from each geological period.

The complete report illustrates nearly all known species and contains an extensive bibliography.

GEOLOGY AND IRON ORES OF STEEP ROCK LAKE, ONTARIO

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Mining operations at Steep Rock Lake have cast new light on the geology of this long-famous Precambrian area.

The Steeprock Group lies unconformably upon a granitic complex ("Laurentian") and consists of: (1) basal conglomerate (not everywhere present); (2) dolomite and limestone; (3) the "ore zone" (the lower part is chiefly manganiferous waste with minor iron ore, the upper part is chiefly iron ore

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with minor nonmanganiferous waste); (4) "ash rock" (a basic pyroclastic containing minor flows and tuffs); and (5) interbanded flows, tuffs, and sediments (of possible Steeprock age).

All these (as well as younger basic intrusives) have been steeply tilted, more or less altered, and show foliation or brecciation in appropriate rock types. Such features (plus sporadic pyritic replacement lenses along and near the hanging wall of the "ore zone") are ascribed to the emplacement of a post-Steeprock ("Algoman") batholith 5 miles distant. Several major faults cross the area, the largest of which has caused a strike separation of more than 2 miles.

The "ore zone" holds all the known iron ore bodies, is up to several hundred feet in width, and shows remarkable continuity and uniformity wherever explored. The lower part rests in erosional disconformity on the carbonate and is largely of residual derivation. The upper part is chiefly goethite and contains narrow bands of cherty, sandy, and aluminous sediments. The most common type of breccia has fragments of very fine-grained goethite surrounded either by coarsely crystalline goethite or by hematite. The field relations, mineralogy, and paragenesis suggest that the ore bodies may represent sedimentary limonite of Steeprock age, brecciated by compaction and folding, with the more finely comminuted matrix recrystallized or modified by hydrothermal solutions, locally producing migration of iron.

GEOLOGIC ASSOCIATIONS OF NIOBIUM IN THE UNITED STATES

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The element niobium is commonly referred to as columbium in commercial usage and in the older American technical literature. United States niobium production, which has been small, has been from pegmatites; but placer deposits containing radioactive columbates are being developed in Idaho.

Niobium concentrations in the United States are found in the following environments: (1) pegmatites; (2) placers containing columbate minerals; (3) titanium deposits in alkalic igneous rocks, involving the minerals rutile, brookite, perovskite, and sphene; and (4) various accessory minerals—especially sphene, ilmenite, and rutile—in igneous and metamorphic rocks.

Rutile and brookite from the alkalic complex of Magnet Cove, Arkansas, and rutile from the alkalic rocks of the Marfa area in Western Texas contain between 1 and 5 per cent Nb. These deposits have recently been studied by the U. S. Geological Survey. Rutile from other sources generally contains less than 0.1 per cent Nb. Ilmenite associated with anorthosite in Virginia, New York, Quebec, and elsewhere contains generally less than 0.01 per cent Nb. Perovskite from Magnet Cove contains much more niobium than that from the similar alkalic complex at Iron Hill, Colorado. Sphene in Arkansas syenite, the parent rock of the bauxite deposits, contains as much as 0.6 per cent Nb and is apparently the source of the niobium in the bauxite. The Geological Survey is studying accessory minerals of ore or potential ore to confirm or refute the possibility of other concentrations of niobium. It is suggested that mining companies should investigate the niobium content of their titanium-bearing minerals.

APPROACHES TO THE STUDY OF LEAD-ZINC GOSSANS

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Current approaches to the reconstruction of lead-zinc gossans into their original primary ores include many not available during the early studies of Locke, Blanchard, and Boswell. Several of these were selected and tested in the field and laboratory. Of considerable value was the quantitative consideration of gossan porosity using both standard measurements and modified Rosiwal counts. Color criteria proved of local value but could not be transferred from one district to another. As all

gossan "limonites" so far tested are goethite, the mineralogy of the hydrous iron oxides proved of little aid in predicting primary mineralogies or in distinguishing transported from indigenous "limonite." Processes and rates of oxidation of lead and zinc ores were reviewed by experimentation and could be clearly related to grain size and E.M.F. effects. The formation of zinc carbonates as against zinc silicates in the oxide zones seems to be determined by climatic factors.

ORNAMENTATION AS A SPECIFIC CHARACTER OF OSTRACODS

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Many Paleozoic ostracods have been assigned to species according to the nature of their reticulation, tubercles, denticles, spines, punctae, or other ornamentation. Inasmuch as it is one of the characters considered essential for specific determinations, ornamentation should be studied for constancy within species.

Four factors affect the size, number, and distribution of features of ornamentation: (1) instar—ornamentation increases during ontogeny, so that older ostracods have features not found in the younger, and adults are the most highly ornamented instar of the species; (2) sex—in some dimorphic species, the ornamentation is not quite the same in males and females; (3) individual variation—some species show a gradation from specimens with almost smooth valves to those that are highly ornamented; and (4) preservation—in fossil ostracods of one species, instar, and sex, the preservation can greatly affect the nature of the ornamentation. In some species one kind of ornamentation occurs in a thin outer layer and a completely different kind in the layer below. The thin outer layer may be the replacement of the original chitin coating of the valves by calcium carbonate during fossilization. Some specimens have the thin outer layer preserved, and some do not, so that two kinds of ornamentation can occur in one species. In addition, corrosion after fossilization can reduce the size and change the shape of papillae or tubercles and may efface many structures.

Each species must be studied independently to determine the causes of variation in its ornamentation. Variations in one species may be attributed to more than one factor, and those in two species from the same bed attributed to different factors.

OCCURRENCE, DISTRIBUTION, AND WEATHERING OF PYRITES IN COALS FROM THE SYDNEY COALFIELD, NOVA SCOTIA*

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The nature and occurrence of pyrites in coal is studied by the polished-surface technique using high-power, oil-immersion objectives.

Pyrites occurs in greatest abundance in finely disseminated form, although lenses and bands, sulfur balls, and veins along cleats and joints are well known.

Disseminated pyrites consists of cubic, globular, prismlike, stellated, and irregular particles. These forms are found as individual particles, clusters, aggregates, and massive patches. The prismlike and stellated forms have been identified as marcasite by x-ray analysis.

The amount of disseminated pyrites varies both horizontally and vertically. The vertical changes in concentration may be either sharp or gradational. In any event, well-defined benches of high-sulfur coal are often evident in the seams.

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In some instances, benches and bands high in marcasite occur and occasionally extend laterally for considerable distances. One exceptional occurrence can be traced laterally for 11 miles. Successive layers of marcasite and pyrite can possibly be accounted for by changes in the pH of the swamp waters at the time of deposition.

The particle size of the disseminated pyrites generally falls between 10 and 50 microns, but particles only a small fraction of a micron in diameter sometimes are abundant. The rapid oxidation of pyrites in coal can be related to particle size alone. Particles below the range of 1–3 microns weather rapidly, while particles larger than this critical range do not weather under laboratory conditions.

PEDIMENTS OF THE LITTLE ROCKY MOUNTAINS, NORTH-CENTRAL MONTANA

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The Little Rocky Mountains, an isolated cluster of peaks in the plains of north-central Montana about 70 miles south of the Saskatchewan boundary, are surrounded by gravel-strewn pediments formed by the several streams issuing radially from the mountains. The mountainous area is underlain largely by resistant rocks, including Precambrian schist and gneiss, early Tertiary alkalic porphyry, and Paleozoic sedimentary formations that range in age from Middle Cambrian to lower Mississippian and consist chiefly of quartzite, limestone, and dolomite. The pediments are underlain chiefly by the less resistant strata—mostly shale, marl, and sandstone—of several Mesozoic formations; the gravels upon them are composed of fragments of the hard materials exposed in the mountainous area. Each pediment has been formed by a cycle of aggradational and degradational processes, in which floodplain building by one of the main streams alternates with piracy of this stream by one of its own tributaries.

FLOAT BLOCKS IN TERTIARY VOLCANICS OF SOUTHERN NEW MEXICO*

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Two large float blocks of Permian limestone occur within Tertiary pyroclastics in the Selden Hills. The Selden Hills is an uptilted, north-south elongated fault block bordering the Rio Grande depression in southern New Mexico, 22 miles north of Las Cruces. The float blocks are thin plates of Permian Hueco limestone that overlie mid-Tertiary latitic and andesitic tuff-breccias. The larger limestone plate is 2100 feet long, 1600 feet wide, 150 feet thick, and weighs about 42 million tons. The basal parts of the two plates are brecciated, silicified, and hematitized, while the upper parts are shattered along many small faults and are partly marbleized.

There are only a few limestone xenoliths in the tuff-breccia, the limestone is not intruded by the latite, and the dip of the limestone beds diverges about 20° from the dip of the volcanics. Late Cenozoic deformation in the area consisted of normal faulting and gentle folding; overthrusting is not known. The limestone plates, therefore, are believed to be float blocks, moved from an initial crater rim by floating on top of and partly within a cool glowing avalanche, a clastic flow as described by Zies (1938, p. 14). The nearest outcrops of Hueco limestone are 11 miles to the south and southeast. The float blocks, however, probably traveled a shorter distance, and their source is now buried under the late Tertiary sediments that surround the Selden Hills.

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CONGLOMERATES ASSOCIATED WITH THE CUBITAS PLATEAU, CUBA

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Two penecontemporaneous conglomerates associated with the Cubitas Plateau, previously interpreted as reworked breccias along the sole of a southward-moving erosion thrust, were derived from two different terranes and deposited under different conditions but in response to the same sequence of tectonic events: compression, imbrication, and northward high-angle overthrusting of the southern margin of the Upper Cretaceous-Paleocene Cubitas basin.

One of the conglomerates, stratigraphically and structurally conformable with the basin structures, started as an influx of serpentine coarsening stratigraphically upward and detrital during the deposition of the youngest member of the Cubitas limestones. It grades through sands, gravels, and cobble-sized angular conglomerates of serpentine and Paleocene to Middle Eocene limestones. Formed along submarine fault scarps and deposited at the edge of the Cubitas basin, the conglomerates were reworked with a northward shift of the fault zone and subsequently infaulted with the older basin deposits during thrusting.

The other conglomerate, with only pre-Danian constituents, none from the Cubitas basin, lies as a thin veneer in the Senado Plain between the Camajan Hills and the Cubitas Plateau. It consists of locally derived angular limestones—"Aptychus" and "Camajan"—and a wide assortment of igneous, metamorphic, and sedimentary roundstones derived from farther south, embedded in an unfossiliferous marly matrix, unconsolidated but sorted and bedded with a steep southern dip. Vertical diapirs of remobilized serpentines crosscut and disturb the deposits. During the deformation of the Cubitas basin, sharpstones derived from terrestial fault scarps along the reverse slopes of the imbricate fault blocks were deposited together with roundstones from previous erosion cycles, brought into the area prior to the deformation.

The deposits of the Cubitas basin were raised from late Tertiary on along normal faults to form the present plateau. The conglomerates in the Senado Plain were tilted, and the shallow serpentines mobilized beneath and squeezed into the conglomerates.

EXPERIMENTAL STUDIES OF RHEOMORPHISM

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In order to study the successive melting of natural rocks, specimens of granite, syenite, gabbro, diabase, and peridotite were heated to the melting temperature of minerals present. The rock was kept at constant temperature for periods ranging from a few hours to 10 days. After quenching, the rock was studied in thin section. Tests were run in air, CO, CO_2, H_2O, and city gas.

In all tests the ferromagnesian minerals started to melt earlier than feldspar and quartz. In the thin sections the mafic components could be seen converted into glass. At the same temperature the felsic components were unaffected, if we disregard optical changes. Biotite and chlorite seem to be the first minerals to melt.

In a gas furnace the melting starts 200°–300° lower than in an electric furnace and air. In an electric furnace an atmosphere of H_2O and (or) CO did lower the melting temperature. A reducing atmosphere seems to cause an early melting of minerals containing iron and magnesium. The time of heating did not affect the temperature of melting. The grain size may have a considerable effect.

The sequence of melting in natural rocks thus does not under all conditions correspond to the sequence of crystallization found in artificial melts. The experiments seem to throw some doubts on the theory that aplitic and granitic material is formed by means of partial anatexis. They explain certain structural features in volcanic and plutonic rocks.

NEW AGE DETERMINATIONS BY THE LEAD METHOD

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Ages of a number of radioactive minerals have been determined from Pb^{207}/Pb^{206}, Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{208}/Th^{232}, and Pb^{206}/Pb^{210} ratios. Values obtained for minerals from classic localities such as Joachimathal, Belgian Congo, and Central City, Colorado, agree well with those reported by other investigators. The apparent anomalies in the ages of a given mineral computed from various possible isotope ratios can be understood with the aid of radon leakage and common lead isotopic data. Uranium leaching does not appear to be a significant source of error in most cases. Radon leakage is significant in many cases and is responsible for the high ages commonly given by Pb^{207}/Pb^{206} ratios.

MOLLUSCAN FAUNAS OF THE EOCENE COLTON AND GREEN RIVER FORMATIONS, CENTRAL UTAH

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The Eocene Colton and Green River formations generally overlie the Flagstaff formation in Central Utah although they are often in complex intertonguing relationship with it and with each other. The genera represented in the Colton formation are *Elliptio*, *"Helix,"* *Australorbis*, *Gyraulus*, *Physa*, *Viviparus*, and *Goniobasis*; the same genera, with the exception of *Elliptio*, are also found in the Green River formation. All these genera, except *Australorbis*, are also present in the Upper Flagstaff formation. The Colton and Green River faunas may be thought of as directly descended from the Flagstaff faunas; specific and subspecific forms evolved in the same general region as in Flagstaff time, but its lakes were isolated from other areas of molluscan development during Colton time and only briefly connected with them during Green River time, permitting *Australorbis* to migrate into the region.

The development of these molluscan faunas took place in small, shallow lakes of comparatively ephemeral character during Colton time and part of Green River time. In later Green River time, although lakes more extensive than the Flagstaff lakes existed, conditions in them were almost entirely unfavorable to Mollusca, and their remains are found in only a few of the upper Green River beds of the region.

The affinities of the Colton Mollusca are with those of the Upper Flagstaff; characteristic features appear in the genera *Goniobasis* and *Physa* which permit differentiation between Colton and Flagstaff beds; the Green River fauna is characterized especially by the genus *Australorbis* and the relative scarcity of *Goniobasis*.

GEOMORPHOLOGY OF THE ALLEGHENY MOUNTAINS OF EAST-CENTRAL WEST VIRGINIA

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The Allegheny Mountains of east-central West Virginia were imperfectly peneplained in pre-Schooley time. There is no evidence that any external base level has affected this region since uplift of the pre-Schooley surface—*i.e.*, no peneplains controlled by a base level outside the area have developed since pre-Schooley time. The region has been lowered by differential mass wasting ever since this uplift.

Topographic height is a direct function of rock type, thickness, and attitude. Locally, low-relief areas are developed on flat-lying rocks. Homogeneous groups of tilted rocks have been lowered uniformly by mass wasting, so that today they form low-relief surfaces at various levels unrelated to regional base levels.

While the general levels of the rocks in the anticlines are controlled in detail by rock type, the gross elevations are controlled by the level of the streams draining these folds (the level below which mass wasting cannot work). Therefore retreat of caprock waterfalls with little or no loss in height has resulted in local, topographically high, low-relief areas on weak rock above the caprocks.

The position where the streams breach the folds by flowing across the Pottsville-supported ridges is controlled by a tear fault associated with a thrust fault.

PETROLOGY OF THE ROUND LAKE BATHOLITH AND ITS ASSOCIATED INTRUSIVES

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The Round Lake batholith is a composite, elliptical intrusive extending from Round Lake, south of Kirkland Lake, to Matachewan. It is composed of two main phases, a southeastern leucocratic quartz dioritic or trondhjemitic phase and a younger northwestern granitic phase. Both phases are remarkably uniform, massive, and structureless except near contacts with older Keewatin rocks. These features, together with local chilled contacts and contact breccias, are best explained by assuming a magmatic origin for the batholith.

North of the batholith lies a series of syenitic stocks of which the Otto Stock, northwest and north of Round Lake, has been most extensively studied by the author. The core of this stock is very similar in composition and appearance to the granitic phase of the batholith. The major portion of the stock is syenitic, with local marginal phases of coarse pegmatitic texture and, locally, of altered nepheline syenite.

TORONTO SUBWAY: SUBSURFACE INVESTIGATIONS

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As a solution to traffic problems in the business section of downtown Toronto, the first stage of a modern standard-gauge subway system is now being completed by the Toronto Transportation Commission. The first 2 miles consists of a reinforced concrete box structure carrying the two tracks beneath the main S.-N. artery of the city. This was constructed by the "cut and cover" construction method. The remaining 2½ miles are generally in open cut located in private right-of-way. A program of test boring along the subway route was carried out in 1946. Concurrently, a detailed study of all available local geological information and of the records of all previous borings in the vicinity of the route was made. The results of these investigations were used in the preparation of the necessary contract documents. They were carefully checked as construction proceeded. No unexpected subsurface conditions were encountered.

STRATIGRAPHIC STUDIES OF THE ORDOVICIAN SYSTEM IN CENTRAL ONTARIO*

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Recent stratigraphic studies of the Ordovician strata of central Ontario have established the following succession of formations, in ascending order: the Shadow Lake, Gull River, Coboconk, Kirk-

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field, "Sherman Fall correlative", and Cobourg, all of Middle Ordovician age; and the Collingwood equivalent, Gloucester equivalent, Blue Mountain, Dundas, Meaford, and Kagawong-Queenston, of Upper Ordovician age.

The division of the marine section into three groups clarifies certain surface and subsurface relationships. The lowest group comprises a limestone sequence of Black River and Trenton ages for the most part; the middle group consists of the bituminous and calcareous shale section, of Collingwood and Gloucester ages; and the upper group comprises the remaining shales, interbedded shales and limestone, and limestones.

Previously the Black River-Trenton sequence has not been subdivided on a regional, formational basis in this area. In addition to the previously recognized disconformity at the top of the Cobourg, another is confirmed for the base of the Blue Mountain, and minor ones are now known within the Gull River and Cobourg. The base of the Trenton is marked by the widespread occurrence of a clastic fragmental limestone, no break in sedimentation having been recognized. In addition, the Blue Mountain formation has now been mapped from Georgian Bay to Lake Ontario.

CLASSIFICATION OF ECONOMIC DEPOSITS

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A satisfactory classification of economic deposits should be closely related to petrology. The major problem concerns the relationship of economic deposits to the classification of igneous, sedimentary, and metamorphic rocks. Economic deposits transcend the bounds of this rock classification in many places. This weakness lies in the rock classification and not in the real relationship between the valuable and non-valuable materials.

An effective method of classifying economic deposits, in order to minimize confusion in the student's mind, should include a consideration of morphological characteristics as well as genetic relationships. Such a method is presented which utilizes both geochemical and petrologic concepts. The basis for the present modification of the Bateman classification is the chemical differentiation of material on the earth's surface and in the upper part of the lithosphere. As the crustal forms of matter differentiate or recombine, they become the various rocks, some having economically valuable constituents.

Economic deposits can be divided into two main divisions as follows: the major or endogenic cycle and the minor or exogenic cycle.

The major-cycle deposits are formed by the processes of chemical differentiation and recombination solely within the upper lithosphere. The minor-cycle deposits are formed by the differentiation and recombination of matter due to interactions of the uppermost lithosphere, atmosphere, hydrosphere, and biosphere. These two main divisions are further subdivided into classes based on morphologic and genetic characteristics.

REVIEW OF THE FALCONBRIDGE ORE DEPOSIT, ONTARIO, CANADA

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Falconbridge Mine is on the outer edge of the norite-micropegmatite irruptive near its southeast corner. The ore deposit ranges from 5500 to 6500 feet in length and is presently known to the 4000-foot horizon. It is sheetlike and coincides for the most part with the contact of the norite and the older Keewatin greenstones, conforming in strike and dip with this contact. The ore zone is localized along this section of the contact by a strong regional shear coinciding with the contact. This shear appears to be pre-norite in age with post-norite movement. Subsidiary breaks from the main shear produce ore swells which extend into the adjoining walls for relatively short distances. It is concluded that the shear zone provided the channel, or travelway, for the transfer of the ore from its source upward to its resting place, and also, that the shear provided the permeable zone necessary for the

deposition of the ore deposit. It is also concluded that the ore and the pre-ore norite originated from the same magma source.

BASE-METAL DEPOSITS OF NORTHERN NEW BRUNSWICK

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Occurrences of base and other metals have long been known in Northern New Brunswick. Within the past year or so deposits of mineable grade with tonnages to the order of several tens of millions have been discovered and are still undergoing exploration. Intensive prospecting, mainly by ground geophysical methods with guidance by airborne magnetometer surveys, is underway throughout the region.

The ore deposits are in a region of typical Appalachian formations and structures of early to mid-Paleozoic age.

An areal and probably structural, if not genetic, relationship of the ore bodies to intrusions of Devonian granite is apparent.

Some deposits are related to a system of northeasterly and northwesterly shear directions and associated tension fractures. The newly discovered large deposits, trending nearly north-south, are related to broad flexures.

Shearing and fracturing have been localized along contacts of competent intrusions, massive flows, or iron formation, with incompetent argillites, tuffs, or schisted flows.

The major deposits are massive pyrite bodies with pyrrhotite locally prominent. Sphalerite, galena, and chalcopyrite are intimately mixed with and along veinlets in the iron sulfides. A silver content is general. Texture is fine-grained and suggestive of replacement.

Other deposits range from disseminations to massive injections and replacements and from quartz-arsenopyrite-gold veins, through pyrrhotite-chalcopyrite and sphalerite-galena-pyrite deposits with mainly quartz gangue or accompanying silicification and fine- to medium- and/or coarse-grained sphalerite-galena veins with calcite gangue.

OPTICAL AND X-RAY STUDIES OF NATURAL HIGH-TEMPERATURE ALKALI FELDSPARS

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Accurate optic axial-angle measurements have been made on members of the sanidine-anorthoclase series both in their natural state and after heating at 900°C for 24 hours. The mean value of the optic angle of feldspars in the compositional range Or_{100}–Or_{60} decreases and, in the compositional range Or_{60}–Or_{37}, increases as a result of this heat treatment. Those feldspars which are triclinic at room temperature (anorthoclases) show only a very slight increase in the mean value of the optic angle. X-ray studies show that these changes are related neither to unmixing nor to the variation in optic angle of crystals from the same specimen.

The change in the effect of heat treatment on the optic angle at a composition of Or_{60} is correlated with the ease with which the change from sanidine to high sanidine can be accomplished and, at a composition of Or_{37}, with the change from monoclinic to triclinic symmetry.

SHAPE OF ATOLLS: AN INHERITANCE FROM SUBAERIAL EROSION FORMS

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The essential features of oceanic atolls—the annular reef, the basin-shaped lagoon, coral knolls in the lagoon, and elongate reefs bordering channels inside the deep passes—resemble subaerial

erosion forms on existing limestone islands in the tropical Pacific. Such features may control the form of atolls by providing promontories on which reef-building organisms grow after subsidence.

Two processes appear responsible for the limestone solution forms: (1) case hardening (recrystallisation) of steep, exposed limestone surfaces, and (2) comparatively rapid solution of gentler soil-covered slopes. Many limestone islands have a prominent rim along their precipitous outer wall and a basin-shaped central depression. Residual case-hardened limestone pinnacles occur in the central depression. Natural levees of limestone with steep, bare stream-facing banks and gentle soil-covered back slopes occur near the mouths of streams. On these features the main annular reef, coral knolls, and the reefs inside deep passes might develop.

This hypothesis is a modification of the theory of glacially controlled subsidence of Ph. H. Kuenen. Grand subsidence is necessary to account for the thousands of feet of limestone beneath oceanic atolls, and glacial fluctuation provides for periods of subaerial erosion. Kuenen regarded the amount of erosion during the low-water glacial periods as an open question, but thought nearly complete low-level erosion might have taken place. The writer would state specifically that low-level erosion did not take place, but that reefs exposed during the glacial periods were weathered to forms typical of existing limestone islands in the tropical Pacific.

CORRELATION OF THE PRECAMBRIAN ROCKS OF THE SOUTH SHORE OF THE LAKE SUPERIOR REGION

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Correlations of Precambrian rocks in the Michigan, Wisconsin, and Minnesota areas have been modified to conform with results of recent work. The recognition of sedimentary facies changes in Huronian rocks of the Marquette Range may require changes in the correlation of other Huronian rocks in the South Shore Region. Accessory-mineral studies have shown the occurrence of three types of zircon which seem to be related to igneous rocks of Archean, post-Archean and pre-Keweenawan, and Keweenawan ages. New data are presented to somewhat extend the area of previous accessory-mineral studies.

GEOLOGY OF THE PALAU ISLANDS

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The Palau Islands, 550 miles east of the Philippines and 800 miles southwest of Guam, are the exposed crest of one of the arcuate submarine ridges separating the basins of the Philippine Sea and the Pacific Ocean. The group extends 90 miles as a chain from north to southwest and contains about 350 islands with an area of approximately 158 square miles.

The Palau reef, partly barrier and partly fringing, encloses all islands except those of two small atolls to the north and the island of Anguar to the southwest. The islands are of three types: volcanic, high limestone, and low platform and reef. The volcanic islands include Babelthuap, which comprises about four-fifths of the land area of the group, and a few neighboring islands.

The volcanic rocks, chiefly pyroclastic, were erupted from a center on western Babelthuap during late Eocene and possibly Oligocene times, as determined from Foraminifera in marine tuffs. The basalts, andesites, and dacites resemble those of other circum-Pacific volcanic associations. Faults and joints form a well-developed pattern.

To the south, reef and lagoonal limestones, ranging from Miocene to Pleistocene in age, overlap the volcanic rocks. Uplifted as much as 600 feet, they form many islands undercut at sea level by deep notches. Several low platform islands of coralline limestone adjacent to the reefs at the southwest end of the group were raised recently. Many features indicate recent changes of sea level.

Phosphate from Anguar and bauxite from Babelthuap have been mined and exported.

RADIOACTIVE, PRONOUNCEDLY DIFFERENTIATED PEGMATITE SILL, LAC LA RONGE DISTRICT, NORTHERN SASKATCHEWAN

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Five miles east of Hunter Bay, Lac La Ronge, is an irregular pegmatite sill, probably averaging 40 feet thick, intruding metamorphosed sediments. It is composed of three facies: an upper margin 2 inches thick of fine-grained (¼ to 1 inch), chiefly white oligoclase and quartz, next is 10 feet or more of coarse (8 inches) crystals chiefly salmon-pink potash feldspar and white plagioclase, both graphically intergrown with quartz; and, a central band 4 feet, or more, thick of salmon-pink microcline-perthite crystals up to 2 feet long with interstitial glassy quartz and a little muscovite. The same two outer zones are repeated below the central zone.

The central two facies are not radioactive, but the outer selvedge and immediately adjacent coarse mica schist are notably so in places. At a gablelike part of the upper contact of the sill, over a length of 8 feet, and over a width of 1–4 inches numerous uraninite crystals up to 1 inch in diameter have been obtained. This uraninite is low in thorium. Another part of the upper contact has a concentration of thorium crystals. A scintillometer survey obtained a number of above-background readings elsewhere near the inferred upper contact of the sill.

Evidently the radioactive material tended to concentrate next to the hanging wall. Presumably it migrated there before the crystallization of the sill was far advanced.

GEOCHEMICAL STUDY OF CHERT AND RELATED DEPOSITS

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Chemical analyses of 24 samples of high-silica sedimentary materials indicate surprisingly similar bulk compositions. Thirteen of the samples are chert; the remainder are novaculite, flint, siliceous oölite, silicified wood, melikaria, and a chalcedony ball from a bauxite deposit. The samples range from Precambrian to Recent and have a wide geographic distribution.

The narrow range of silica, 95.00–99.95 per cent, shows a facility of sedimentary differentiation to produce pure chemical types. Differences in the minor and trace constituents, however, may reflect different environments and geologic processes.

The following ranges in weight per cent were found for major constituents: SiO_2, 95.00–99.95; Al_2O_3, 0.00–1.95; Fe_2O_3, 0.04–0.90; MgO, 0.00–0.49; CaO, 0.00–1.54; Na_2O, 0.00–0.09; K_2O, 0.00–0.33; H_2O, 0.01–1.18; and CO_2, 0.00–1.20. TiO_2, P_2O_5, MnO, and Li_2O are minor constituents. As and Mo range from less than 1 to 10 ppm. Ge is more variable, with an average of about 0.5 ppm for the 24 samples. The average Ba content is about 25 ppm; Sc, Cu, Cr, Ni, V, and Sr range from less than 1 to 100 ppm. Co, Ga, and Sn are present as traces, but Bi, Pb, and Zr could not be detected in any of the samples.

TRIASSIC BASIN IN PENNSYLVANIA AND NEW JERSEY*

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Contact relations at both borders of the Newark basin indicate the pre-Triassic floor had relief of several thousand feet. At the southern border in Chester County, Pennsylvania, the lower 3000 feet of Stockton arkose overlaps westward on the Precambrian floor. At the north border in western

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New Jersey, Paleozoic rocks, faulted down against Precambrian, are overlapped by 3000 feet of Triassic where the floor sloped steeply.

Faults form parts of the northwest border, but most movement occurred before deposition ceased. Sediments accumulated against the escarpment. Fanglomerates identify the present border as nearly the northwestern limit of deposition. At several localities no faults are known, and older rocks are overlapped directly by beds high in the Triassic column.

After the Appalachian orogeny the region was maturely dissected, not peneplaned. Broad valleys, eroded on weaker rocks (chiefly Cambro-Ordovician limestones and shales), became sites of Newark deposition. The present crystalline Piedmont was then a highland, the central massif of the Appalachians. It furnished detritus for Stockton sediments. The northwest border was a steep escarpment, capped by resistant Silurian quartzite, at whose foot alluvial fans formed. Recurrent faulting there deepened the basin, allowing accumulation of several thousand feet of red Brunswick, from northern provenance, after erosion lowered the southeastern highland. The Lockatong lacustrine facies accumulated where the basin was widest, during the earlier part of the period of red-bed deposition in the narrower areas.

OROGENIC AND GRAVITATIONAL TECTONICS IN THE NORTHERN APENNINE MOUNTAINS

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Recent work in the northern Apennines has revealed a stratigraphic and tectonic history departing widely from conventional patterns. Sediments include Upper Triassic evaporites and dolomite, Liassic limestone (Carrara marble equivalent), and thin (±400 m.) deep-sea deposits of limestone, chert, and varicolored shale, Jurassic through Eocene in age. These are overlain conformably by a great thickness (±5000 m.) of Oligocene to middle Miocene "resedimented" clastics, believed by Kuenen and Migliorini to have been deposited from turbidity currents.

Overlying the resedimented clastics are the "argile scagliose," chaotic, slickensided clays carrying exotic blocks and mountainous masses derived from the Tyrrhenean area far to the southwest. Sediments deposited on the "argile scagliose" subsequently moved to the northeast; far-travelled allochthonous sediments locally grade upward into less moved and even into truly autochthonous sediments.

Primary compressional structures are large anticlinal type ranges characterized by parallel belts of thrust faults on the northeast and normal faults on the southwest, converging toward a focus about 10 km deep. Migliorini named these structures "composite wedges" and showed that normal and reverse faults were formed contemporaneously during compression. The ranges are oldest to the southwest and successively younger to the northeast. Submarine sliding of unconsolidated shale and overlying rigid rocks from the flanks of successively rising ranges produced the "argile scagliose," much of which has travelled more than 100 km from its source.

Gravitational sliding and the "composite-wedge" theory of orogenesis account for observed relationships without appeal to great nappes requiring large crustal shortening.

ORE TEXTURES OF URANINITE AND ASSOCIATED MINERALS FROM THE COLORADO PLATEAU URANIUM DEPOSITS

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Uraninite in the ore deposits of the Colorado Plateau is present as a replacement mineral. It replaces the clay cement of the quartz grains, the quartz overgrowths, asphaltite, organic matter, and in some cases sulfide minerals. The exsolution texture of chalcopyrite and bornite indicates deposition

at a high temperature. A comparison of the large amount of alteration at the Marysvale uranium deposit and the low amount of alteration of the Plateau deposits suggests a low-temperature deposition for the Plateau deposits.

QUANTITATIVE GEOMORPHIC ANALYSIS OF DRAINAGE-BASIN CHARACTERISTICS ALONG CLINCH MOUNTAIN, NEAR GATE CITY, VIRGINIA

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Quantitative study of stream length, basin circularity, basin area, drainage density, and hypsometric properties was made along Clinch Mountain, a homoclinal ridge in which dip undergoes considerable variation along the strike. Samples of the form elements were taken from large-scale topographic maps and air photographs, checked by field observations. Significant differences in sample means were determined through analysis of variance.

Along the southeast (dip) flank of Clinch Mountain first- and second-order stream lengths and basin areas show, on the whole, inverse relationship to dip, whereas neither drainage density nor basin circularity is consistently related to dip. Hypsometric curves are dominantly convex upward where dips are low and slightly concave downward where dips are steep. Where dips are higher the mean hypsometric integrals are lower.

By contrast, on the northeast (scarp) flank of the ridge these same form elements show surprisingly little influence of changes in dip. There is a striking inverse relationship between crest height and dip magnitude. In segments of the ridge where dip remains constant, ridge crest maintains an almost constant elevation. Tendency for stream lengths and basin areas to cluster about a mean value may explain the general evenness of ridge crest, without the necessity of postulating peneplanation in an earlier cycle.

VERTICAL ZONING AT THE O'BRIEN GOLD MINE, KEWAGAMA, QUEBEC, CANADA

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A study of bullion assays and mine-production records has indicated a systematic variation in the purity of the gold recovered during the years 1936 to 1946. From 500 to 1200 feet beneath the surface the ratio (gold: silver + gold) $\times$ 1000 has increased from 860 to 920; below 1200 feet the ratio is constant. Between surface and 500 feet the ratio is unexpectedly high (900 to 910); this has been interpreted as due to secondary enrichment.

The proportion of gold recovered by cyanidation as against that recovered by amalgamation during 1939–1946 has increased continuously suggesting that the particle size becomes smaller with depth.

NEW OCCURRENCE OF LEUCOSPHENITE, IN OIL SHALE FROM UTAH

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Leucosphenite, previously known only from the Narsarssuak, Greenland, pegmatite, is a widespread mineral in the Green River formation of Tertiary age in northeastern Utah. It has been found in several cores from oil wells in Duchesne and Uintah counties, and well cuttings indicate a vertical range of several thousand feet. It occurs in brown oil shale as well-formed crystals several millimeters

in length, commonly associated with shortite $Na_2Ca_2(CO_3)_3$. It also occurs with analcime-bearing layers in beds of the Green River formation like those described by W. H. Bradley in 1930. The formula of leucosphenite, on the basis of chemical analysis of the Utah mineral and spectrographic analysis of the type Greenland crystals, is revised to include 3 per cent B_2O_3 (previously missed) and to omit 3 per cent ZrO_2 (previously reported). The formula tentatively proposed is $CaBaNa_2BTi_2Si_4O_{16}$. Morphological and X-ray studies are in progress. The formation of the leucosphenite is believed related to the reaction of volcanic ash with strongly saline solutions as suggested by Bradley for the analcime.

SIGNIFICANCE OF ACCESSORY MINERALS IN IGNEOUS ROCKS

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Contrary to the expressed opinion of many petrologists, most of the common accessory minerals (apatite, zircon, sphene, rutile, iron oxides, pyrite) may be expected to crystallize late in igneous rocks. This conclusion is based on the known association of accessory minerals with pegmatites, on the physical-chemical premise that, other things being equal, constituents in small amount should crystallize late in a complex system, and on evidence from ore deposits of apatite, rutile, and oxides of iron and titanium.

Studies of the frequency of association of accessory minerals with the various essential constituents of igneous rocks, particularly the basic to intermediate varieties, indicate a marked association with minerals, such as biotite and hornblende, which are low in the reaction series of Bowen. In all types of plutonic igneous rocks, the accessory minerals occur most abundantly along grain boundaries, near fractures and cleavages, or with alteration patches in the essential minerals. These relationships, occasional replacement criteria, and the erratic distribution of accessory minerals in thin sections bear out the conclusion that most if not all have crystallized in a late (deuteric) stage of the cooling magma.

Conversely, the association of the accessory minerals with biotite and related minerals in acid rocks implies a late origin for this mineral even in these rocks. The more nearly equal distribution of accessory minerals among the essential constituents of paragneisses as compared with igneous rocks offers a criterion for distinguishing paragneisses from those of magmatic origin.

GEOLOGY AND ORE DEPOSITS OF THE CENTRAL PORTION OF THE LABRADOR PENINSULA

A. E. Moss (for Staff of Iron Ore Co. of Canada)

Within the Labrador Peninsula in northeastern Canada is a belt of rocks tens of miles wide and hundreds of miles long known as the "Labrador Trough". Some 8000 square miles of the "trough" is described in this paper based on the work done by a large number of geologists while employed by privately financed exploration companies during the period from 1936 to 1953.

The "Labrador Trough" is an intricately folded and faulted geosynclinal segment consisting of a great variety of sedimentary and volcanic rocks which have been cut by intrusives ranging in composition from serpentinites to granites. These rocks are considered late Precambrian and in places rest unconformably on an early Precambrian gneiss complex. The stratigraphy in some sections has been fairly well established although correlation throughout the area will require much additional work.

Economically, the most important rocks are the iron-bearing sedimentary members or "iron formation" which throughout the area are believed to occur at the same stratigraphic horizon. The high-grade iron ore is secondary, and most is caused by the removal of silica and the addition of iron to a formation which originally contained about 30 per cent iron. However, some ore extends into adja-

cent formations that contained little or no iron originally, indicating that much iron has been transported. It is not considered necessary to postulate that hydrothermal solutions have played a role in the formation of this iron ore.

TRANSGRESSIONS AND REGRESSIONS OF EARLY ALLEGHENY (PENNSYLVANIAN) SEAS IN INDIANA*

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Most students of Pennsylvanian sedimentation in Indiana and Illinois recognize cyclical deposition and further believe that the coals in the area are immediately underlain by nonmarine rocks and directly overlain by rocks that reflect a marine environment.

Recent lithologic investigations in the lower part of the Allegheny series in western Indiana indicate that the sediments were deposited in transgressive and regressive seas that resulted in an ascending sequence of nonmarine beds—coal (developed in front of the transgressive sea)—marine beds—coal (developed behind the regressive sea)—nonmarine beds, etc. This sequence suggests that deposition occurred under conditions of marine transgressions and regressions along the eastern fringe of the Eastern Interior Basin in early Allegheny time.

Transgressive-regressive conditions prevailed in restricted areas of subdued relief that were intermittently occupied by shallow, epicontinental seas. Such conditions, briefly maintaining in early Allegheny time in western Indiana, developed the following generalized stratigraphic sequence: (1) Arenaceous shale and/or sandstone, (2) underclay developed on nonmarine material, (3) coal, (4) black fissile shale, (5) fossiliferous shale, (6) fossiliferous limestone, (7) argillaceous shale, (8) thin nodular limestone, (9) underclay developed on marine material, (10) coal, and (11) arenaceous shale and/or sandstone, lithologically similar to (1).

DISORDER IN THE SUPER-LATTICE OF EKMANITE

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The chemical composition and differential thermal-analysis data of ekmanite suggest that this flaky, hydrous-iron-manganese silicate mineral is related to the layer-lattice silicates. The results of single-crystal x-ray investigations indicate that ekmanite possesses a structure that is essentially a packing of talc-type sheets and interleaved cations and that the orthohexagonal cell is a multiple of a subunit of the following dimensions: a = 5.54 A, b = 9.60 A, and c = 12.08 A. The multiplicity of this subunit is present along all three axes, resulting in a super-lattice. The distribution of diffuse reflections indicates the presence of a disordered lattice related to random and irregular displacements of the structural layers along the a and b axes. This effect can be inferred from the rotation diagrams of ekmanite, taken by rotating the crystal around the b axis, which show diffuse streaks along all the layer lines, and also from normal-beam equatorial Weissenberg photographs, taken by rotation around the b axis, which show that the h0l reflections are spread out along curves of constant h and continuously varying l indices.

The chemical composition, DTA curves, and the results of the x-ray investigations suggest a relationship between ekmanite and stilpnomelane.

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GRENVILLE FRONT IN THE BETHOULAT LAKE AREA, MISTASSINI TERRITORY, QUEBEC*

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The Bethoulat Lake area lies across the boundary between the Superior and Grenville structural provinces of the Canadian Shield. It is located immediately northeast of the Lake Mistassini basin, which is underlain by rocks of the Late Precambrian Mistassini series.

Temiscamie River valley, which bisects the area along a north-northeast line, is the locus of an east-dipping zone of reverse faulting that separates two structurally and lithologically distinct complexes. West of the fault zone, the east-trending Superior complex consists of a belt of Timiskaming-type (greenschist facies) metasedimentary rocks flanked on the south by intrusive trondhjemite and on the north by mixed rocks and "porphyritic" microcline granite. East of the fault zone, the northeast-trending Grenville complex consists of paragneiss and amphibolite, a charnockitic (granulite facies) series, and a beltlike body of biotite granite gneiss. Within the fault zone, a cataclastic facies of the biotite granite gneiss contains inclusions of trondhjemite from the Superior complex.

The Grenville complex originated far to the southeast and was thrust northwestward against the Superior complex during some phase of mountain building within the Grenville province. The biotite granite gneiss was intruded or palingenetically mobilized along the active zone of dislocation and crystallized when not far removed from its present structural position. Hydrothermal mineralization in the Mistassini series may be related to this granite gneiss. The reverse faulting along Temiscamie River valley represents final adjustment between the two complexes in post-Mistassini time.

LATE PLEISTOCENE GLACIATION IN NORTH-CENTRAL QUEBEC

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There is evidence that an ice sheet persisted in the highland region of north-central Quebec into very late Pleistocene time, and it is believed that this remnant readvanced at least as far south as the Chibougamau district.

Striae, grooves, and glacial erratics all indicate a general southwesterly movement of the ice. The trend of attenuated, parallel ridges shows that the last advance was approximately S.30°W. from the Nichicun area to Lake Mistassini. The advance of lightly loaded ice created a drumlinized till-pain topography characterized by corrugate ridges, drumlins, rock drumlins, and large drumlinoid ridges of an unusual type.

The ice sheet wasted mainly by stagnation rather than by frontal retreat. During this period, well-sorted outwash sand was deposited in the principal meltwater channels, and well-stratified, interbedded, ice-contact deposits were laid down in the immediate proximity of the wasting ice.

The eskers of the region include the normal type as well as giant, reticulated forms. The latter form conspicuous topographic features since the crests are as high as 200 feet above the sand plains and the widths at the base vary from an eighth of a mile to a mile.

Terraces and beach ridges in the unconsolidated drift as well as wave-cut strand lines and caves on bedrock ridges afford good evidence that Lakes Mistassini and Albanel are the modern remnants of a formerly more extensive glacial lake.

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STRUCTURAL-CHEMICAL CLASSIFICATION OF THE CHLORITES: THE MAGNESIAN CHLORITES

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As a result of the extension of previous hydrothermal studies in the system MgO-Al_2O_3-SiO_2-H_2O single homogeneous crystalline phases have been synthesized along the chrysotile-amesite join as far as the amesite composition. At lower temperatures phases with the 7Å antigorite structure are formed. X-ray data that show the change in unit-cell dimensions accompanying the addition of alumina along the join are given. A single phase of the amesite composition is formed only above 300°C, while below this temperature boehmite + an aluminous serpentine form. Above 450°C all compositions more aluminous than chrysotile yield a more stable 14Å phase, presumably with the chlorite structure. The equilibrium decomposition temperatures of the 14Å phases have been determined. Experiments with natural materials indicate that these, too, probably undergo the antigorite-chlorite dimorphism.

These results substantiate Tschermak's concept of an isomorphous series between serpentine and amesite. The dimorphism between the antigorite and chlorite structures suggests a new structural-chemical classification for at least the magnesian chlorites.

ORDOVICIAN STRATIGRAPHY AND PALEONTOLOGY OF THE NORTHERN HUDSON BAY LOWLANDS*

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During field work for the Geological Survey of Canada in 1950 and 1951, faunal and stratigraphic studies were made along the Churchill, Nelson, North, and South Knife rivers. Highly fossiliferous limestones containing representatives of the Red River and Stony Mountain formations are well exposed, particularly on the Churchill, where they attain a possible thickness of 300 feet. The Churchill River Ordovician succession is designated as the standard for the Hudson Bay Lowlands. The Red River equivalents, which are about 150 feet thick, contain Foerste's (1928) Dog Head and Cat Head members, but his Selkirk member is missing. The occurrence of *Favosites* sp. in the Dog Head and ***Beatricea nodulosa*** Billings in the Cat Head representatives strongly suggest a Richmond age for the Red River formation.

The Stony Mountain equivalents, which have a probable thickness of 150 feet, appear to contain representatives of all four of Okulitch's (1943) members. The fauna suggests that the upper part of the Stony Mountain is probably Gamachian in age.

Overlying the Stony Mountain, on the Churchill, with an abrupt change in lithology are unfossiliferous dolomites which are questionably referred to the Silurian.

STRUCTURAL CONDITIONS IN COAL MINES OF THE SOUTHERN CANADIAN CORDILLERA*

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Fault and drag-fold patterns in the lower Cretaceous bituminous coal seams of the Crowsnest and Cascade coal areas may be interpreted by the mechanics of shear thrusting. Gentle flexing of the overriding masses was effected through similar folding for the combined series of competent and in-

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competent units. Consequent alternate stretching and compression of the coal-bearing sequences resulted in the development of a profusion of extension and contraction faults of small stratigraphic throw (generally less than 10 feet), and a sheared condition within the coal. Frictional resistance retarded those beds in the overthrust masses closest to the thrust planes so that in every instance the upper beds moved slightly farther east relative to those below them. Consistent drag-fold patterns within the coal were the result.

That these minor faults are apparently genetically related to the regional structures of the coal fields is borne out by the common trends of the major and minor structures, the directions of slickensiding, and the near absence of these minor faults in the relatively undisturbed seams of the Alberta syncline.

STUDIES OF MINERAL SULPHO-SALTS: XVIII—PAVONITE, A NEW MINERAL

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Alaskaite (Koenig, 1881) from the Alaska Mine, Colorado, which was said to be a Bi sulphide of Pb, Ag, and Cu was shown by Thompson (1950) to be a mixture of several minerals including aikinite ($PbCuBiS_3$) and matildite ($AgBiS_2$). A second occurrence in Sur-Lipez province, Bolivia (Ahlfeld with an analysis by Herzenberg, 1926), Thompson identified as benjaminite by x-ray powder patterns.

Single-crystal studies of more favorable material show that, despite a marked similarity between the powder patterns of type benjaminite from Nevada and the Bolivian mineral, the two are distinct species:

Nevada	a′ 13.34	b′ 4.06	c′ 20.25 A	β 104°
Bolivia	a 13.35	b 4.03	c 16.34 A	β 94½°

An x-ray fluorescence analysis and fusion experiments indicate the composition $AgBi_3S_5$ ($Ag_2S \cdot 3Bi_2S_3$) which is different from that of known sulpho-salts. The Pb and Cu of Herzenberg's analysis are accounted for by the presence of aikinite and chalcopyrite.

Since the type alaskaite has been discredited and its name and supposed composition are not applicable to the Bolivian mineral, it is proposed to name the new species pavonite from the Latin pavo for peacock, in honor of the late Professor M. A. Peacock.

ANALYSIS OF THE DIKE PATTERN OF THE SPANISH PEAKS AREA

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Several intrusive bodies surrounded by an aureole of dikes occur along the eastern border of the Rocky Mountains. Among these the pattern of dikes emanating from the Spanish Peaks is made unique by its peculiar shape. The dikes are symmetrical about a line perpendicular to the front of the Rockies; they curve eastward, and the westward trending dikes are much shorter than the eastward.

E. M. Anderson gives a theory which postulates that dikes will form along planes normal to the direction of least principal stress. On the basis of this theory it is possible to analyze the stress field in the earth's crust during injection of the dikes. This stress field is in very good agreement with the field resulting in a semi-infinite plate, compressed in a direction perpendicular to its boundary and pierced at some distance from the boundary by a circular hole, in which hydrostatic pressure is exerted. Omission of the stresses perpendicular to the boundary leads to a dike pattern bearing no resemblance to that surrounding the Spanish Peaks.

BIOSTROMES AND BIOHERMS OF THE ONONDAGA LIMESTONE IN NEW YORK

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The lowest stratigraphic unit of the Onondaga formation in New York is a light-gray, coarsely crystalline fossiliferous limestone. It is sharply set off lithologically and faunally from the rest of the formation.

At most exposures this member is a true coral biostrome, formed principally of solitary rugose corals. Most individual corals are overturned but show little sign of post-mortem wear. Crinoid debris fills the interstices between the corals and becomes dominant in the upper part of the member. Tabulate corals are common, and several species of brachiopods are of some importance.

Locally, in both western and eastern New York, the member swells into biohermal form. These are massive, dome-shaped structures with indistinct, irregular bedding, formed by the succession of coral colonies. These reefs are up to 70 feet in thickness but are believed to represent the same amount of time as the surrounding, thinner biostrome. The bioherm fauna is dominated by colonial rugose corals although solitary rugose and tabulate corals are common. Some evidence of reef flank beds with a trilobite-gastropod-brachiopod fauna has been found.

Although of constant lithology the member contains both biostrome and bioherm facies. These bear faunas of varying building potential. The solitary corals were prolific but not capable of building above the general level of deposition, and were frequently overwhelmed by influxes of mud. Locally, colonial rugose corals were active enough to construct above the general deposition level where they were protected from inorganic sedimentation.

PETROLOGY OF THE CHARNY FORMATION, LOWER CAMBRIAN, NEAR QUEBEC CITY, CANADA

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The Lower Cambrian Charny formation of the Quebec Group is made up of thick-bedded, massive, red shales; gray, green, and black thin-bedded siltstones; and gray or green "sandstones", which are in beds from 6 inches to 40 feet thick. All the rocks accumulated in moderately deep to deep water. The red shales, which contain hematite, illite, and chlorite, were river-borne sediments carried into the basin of deposition. The siltstones, which have glauconite and collophane, were normal marine sediments. The sandstones, which are interbedded with the shales and siltstones, are a distinctive and significant part of the formation. They are poorly sorted and are from sandstone to conglomerate grade. Their cement was clay (illite and chlorite), but much of it has been replaced by a mosaic of grains of carbonate, which has also replaced plagioclase and potassic feldspar. The sandstones were formed by subaqueous, downslope, mass movement of sediments that had been deposited in marine water. Medium-grained sandstone, now concretions in Charny conglomerates, shows the fabric and composition of some of the original beds. The inferred origin for the sandstones is substantiated by the crumpling, fluting, and planing of the tops of beds. Local and small lenses of well-washed sandstone are submarine spring deposits formed by water pressed out of the compacting sand flows.

MOTTLED CARBONATE ROCKS IN THE MIDDLE DEVONIAN OF EASTERN NEVADA

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Three types of mottling are present.

The sequence of development of laminar mottling includes the following stages: (1) deposition of

dark laminated aphanitic calcilutite; (2) growth of light-colored zones of dolomite outward from intralaminar surfaces, the zones connecting across the laminae to isolate tabular remnants of the original rock; and (3) dolomitization of the remnants giving rise to a tan or light-gray fine crystalline dolomitic rock mottled by medium-fine crystalline dark-brown or dark-gray calcitic bodies. The margin of any given mottle may be both sharp and gradational.

Mottling also results from the roiling or intense local, small-scale deformation of the plastic laminated sediments during or after any of the foregoing stages. In this process the pattern results as the light and dark laminae are torn apart.

Very irregularly shaped mottles, commonly with very gradational margins, result when a relatively homogeneous calcilutite is dolomitized progressively from several scattered centers.

Evidence of dolomitization of plastic sediments is found in the roiled structures and in the intrusion of light-colored dolomite into laminar remnants of calcitite. The rates of deposition and compaction of these calcilutites were such that under the prevailing physical and chemical conditions dolomitization could not proceed to completion.

GEOLOGY OF THE RADIUM HILL URANIUM MINE, SOUTH AUSTRALIA

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The Radium Hill Mine, originally worked on a minor scale for its radium content, has been intensively tested by drilling, sampling, and exploratory development over the past 10 years and is now a significant producer of uranium ore. The ore mineral, which is the titanium-uranium complex davidite, occurs in association with rutile, ilmenite, bronze biotite, and quartz in a series of subparallel lodes which are late-stage replacements in shear planes. The shears are located near the axial plane of a regional dome in early Precambrian metasediments. The strike of the shears is slightly undulatory, and dips range from 40° to 70°.

The distribution of the ore within the lode channels is in irregular shoots though with some suggestion of over-all pitch.

The area has been a locus for numerous phases of igneous activity some of which are considered significant in the localization of ore.

ABUNDANCES OF URANIUM AND THE ISOTOPES OF LEAD IN THE EARTH'S CRUST AND METEORITES

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Data have been obtained for the abundances of uranium and the isotopes of lead in basaltic and oceanic materials. The isotopic compositions of lead from the Columbia River basalt and of recent lead from the Pacific Ocean are 206/204 = 18.12, 207/204 = 15.45, 208/204 = 38.08, and 206/204 = 19.04, 207/204 = 15.69, 208/204 = 39.00 respectively. A study of uranium and lead in meteorites has been reported by Patterson, Inghram, Tilton, and Brown. The cosmic abundances of uranium and lead are estimated to be 1×10^{-4} atoms and 8×10^{-3} atoms per 10^4 atoms of silicon respectively. The composition of primordial lead, if it can be inferred from that in an iron meteorite, is 206/204 = 9.41, 207/204 = 10.27, 208/204 = 29.16. It is possible to make the following interpretations from the above data: nearly all the uranium in the earth is concentrated in the outermost layer of the crust; this concentration was established when the earth was formed; the U^{238}/Pb^{206}, Pb^{207}/Pb^{206}, and Th^{232}/Pb^{208} ages for the earth's crust have values greater than 4 billion years. Basalt may originate from a material from which, during the life of the earth, some uranium has been removed.

TRAVERTINES AND CAVE DEPOSITS OF THE KAAP ESCARPMENT OF SOUTH AFRICA, AND THE TYPE LOCALITY OF *AUSTRALOPITHECUS AFRICANUS* DART

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The surface travertines, included cave deposits, and other associated phenomena along the Kaap escarpment (Campbell Rand) of the Union of South Africa are mapped and described with emphasis on chronology. The four principal travertines at Buxton in the Taungs Native Reserve, type locality of *Australopithecus africanus* Dart, are of different ages and are related to each other and to water-cut channels in such a manner as to represent a long, seven-stage sequence of events, the first of which probably antedates Middle Pleistocene time. Several cave faunas, including the *Australopithecus* fauna, and archeological material of Middle and Late Stone Age of South Africa are correlated with the travertine sequence. The *Australopithecus* fauna occurs in the youngest part of the oldest travertine. Other travertines and associated phenomena along the Kaap escarpment are correlated with the Buxton sequence of travertines, and a tentative correlation is made with the diamond gravels of the Vaal River. Buxton travertines seem to have been formed during the waning of wet (pluvial) periods; on this basis, two earlier, major travertines and two later, minor travertines of the four at Buxton correlate with the two earlier, major pluvials and the two later, minor pluvials interpreted from the gravels and terraces of the Vaal by Cooke. On the basis of physical and biological data accumulated, *Australopithecus* and associated faunas are judged to be no older than the Pleistocene and probably no older than Middle Pleistocene. There is no concrete evidence for a Pliocene age.

METAMORPHISM RELATED TO PEGMATITES IN THE GRENVILLE

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Study of wall rocks of pegmatite intrusives near Bancroft, Ontario, indicates the presence of at least two stages of metamorphism:

(1) An older, regional type, which produced diopside pyroxenites and amphibolites in lime-magnesium sediments and hornblende-plagioclase gneisses from argillites.

(2) A younger local effect associated with swarms of pegmatite intrusives, appearing as zones of alteration extending to as much as 2 miles from the pegmatite. The alteration appears as metasomatic replacement with the gradual appearance of scapolite, oligoclase, and microcline in the pyroxenites and amphibolites and microcline and quartz in the gneisses.

A general study of pink gneisses in the Grenville indicates that their association with pegmatites is constant; it is concluded that the effects seen near Bancroft are typical.

CRINOID *SACCOCOMA CRETACEA* BATHER IN THE GULF COAST CRETACEOUS

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About 50 calyces of the small pelagic crinoid, *Saccocoma cretacea* have been collected from the Gulf Coast formations of upper Taylor and Navarro age. Many of them are exceptionally well preserved and show structural details that were unknown to Bather: The calyces show no evidence of arm facets. The five radially placed summit plates overlap along their left margins, and they probably could be opened and closed much like the shutter of a camera. When the plates were closed over the summit the only access to the interior was along the contacts of the overlapping plates.

RESTUDY OF THE GENUS *FISTULIPORA* THROUGH HALL'S TYPES*

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Type specimens of species of *Fistulipora* McCoy and *Lichenalia* Hall from the Hamilton (Middle Devonian), designated by Hall and by Hall and Simpson, have been redescribed and refigured. The original descriptions and illustrations of these forms were in general vague and contradictory; consequently, these species were heretofore virtually valueless for comparative paleontological studies.

The study of these types suggested a revised generic description that emphasizes four types of interzooecial tissue in longitudinal section, namely: (1) crescentic, imbricating vesicles, convex upward, (2) adjacent columns of interlocking, serrated elements, (3) adjoining columns of superimposed, somewhat flattened, rectangular elements, and (4) a confused mass of irregularly arranged, imperfectly crescentic vesicles and slightly rounded, subquadrate vesicles.

The character of the lunarium is also a most significant feature for specific identification. The conical lunarium is conspicuously thickened in *F. umbilicata* (Hall) but is represented in *F. plana* (Hall) merely by a thickened portion of the zooecial wall; other species exhibit lunaria intermediate in form and prominence between these extremes.

Three new species, based on specimens collected by Hall, have been described. *F. confusa* (Hall and Simpson), *F. crassa* (Hall), *F. interaspera* Hall and Simpson, *F. maculosa* (Hall), and *F. ramosa* (Hall and Simpson) are common to Hamilton rocks in southwestern Ontario and New York.

REGIONAL SEDIMENTARY SAMPLING DESIGN†

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Statistical design can provide measures of reliability of sample estimates of quantitative sedimentary parameters and help maximize the efficiency of regional sedimentary sampling. Through choice of a suitable grid or frame, statistical design permits selection of a small sample of the total available population minimizing the local clustering of sources of information derived from exposures or wells. The hierarchical case of the analysis of variance estimates components of variability on each of several levels of sampling and can be used to determine confidence limits for estimates of mean values for each sampling level. Maximum efficiency of sampling effort results from balancing the cost of observations against the relative variability among sampling levels.

Using torrential cross-bedding as a measure of the direction of sediment transport, these principles of design are applied to 260 miles of Lower Pennsylvanian outcrop of the Eastern Interior Basin. The generality of this method is further suggested by its application to a comparative study, based on electric-log data, of Upper Mississippian and Lower Pennsylvanian stratigraphic variability over a 2916-square mile area of the Eastern Interior Basin.

SOURCE OF SEDIMENTS: APPLICATION OF VECTOR AND SCALAR PROPERTIES

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Determination of the sources of sediments is a major geologic problem. Although scalar properties such as dominance of clastics, texture, and mineralogy have received emphasis in the past, vector properties such as cross-bedding and flow markings merit equal or greater attention. The relative

* The research was conducted at the Royal Ontario Museum of Palaeontology, Toronto
† Published by permission of the Chief, Illinois Geological Survey, Urbana, Illinois

availability between surface and subsurface information determines which criteria are most useful. Where surface information dominates, the study of vector structures, mineralogy, and texture is of most value. Where subsurface information dominates, the study of clastic ratio and shapes of clastic accumulations is more useful. Regional investigations eliminate the effects of local variability for all criteria. The natural unit for regional investigation is the basin or trough. Work in progress indicates that a combination of vector structure and petrographic studies yields the highest ratio of information to effort expended and is applicable to sediments of all ages.

The effectiveness of vector structures and petrology is illustrated in the relatively simple example of a Pliocene fluvial gravel which is characterized by contrasting mineralogical and textural associations and companion contrasts in cross-bedding direction. In the more complex Lower Pennsylvanian sediments in portions of Illinois, Indiana, and Kentucky, the combination of petrographic and cross-bedding studies shows distinct source contrasts and illustrates the generality of this approach.

The establishment of a source-area methodology is important not only for paleogeographic reconstruction, but for the determination of sedimentary trends of economic value and its use in environmental interpretation. Even more important, the determination of source areas bears directly on the problem of peripheral borderlands and current theories of continental growth.

WALL-ROCK ALTERATION IN NORTHWESTERN QUEBEC

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Two main types of alteration accompany the copper-zinc-gold deposits of the Noranda and Bourlamaque districts. Lavas (rhyolites and andesites) and associated minor intrusives (acid to basic) were widely sericitized and silicified. On this phase is imposed a later high-magnesian (chloritic) alteration.

In time and space the first is associated closely with the early pyrite-sphalerite mineralization, the second with later pyrrhotite-chalcopyrite-magnetite. Gold and associated tellurides (the last mineralization) carry no outstanding alteration features but appear most prominently in the magnesian-rich areas. Some ore bodies show all three types (Horne (Noranda) and Quemont); others, two (Waite-Amulet, East Sullivan); a third group, only one (MacDonald, Golden Manitou).

The minerals most closely associated in time and space with the copper mineralization are various chlorites. Progress has been made in the recognition of the variations exhibited by this group, and their relative diagnostic value in ore finding has been partly solved. Also of some value are secondary amphiboles, ottrelite, hsingerite, etc.

One group of ore bodies (Waite-Amulet) is accompanied by a suite of alteration products higher in magnesia than the average. A pervasive spotted sericite-biotite-cordierite alteration (dalmatianite) is cut by a cordierite-rich type with numerous anthophyllite rosettes and finally a chlorite-cordierite rock which is generally nearest to ore.

Study of a considerable thickness of rocks overlying ore has been possible in some cases. It has been found that the escape channels above and beyond an ore body are comparatively minute and can easily be over looked. The zoisite-clinozoisite-epidote group has considerable diagnostic value in such cases.

GEOLOGY AND MINERALIZATION OF THE GRACEFIELD-BOUCHETTE AREA, GATINEAU COUNTY, QUEBEC, CANADA

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The Gracefield-Bouchette area, in the Gatineau River valley about 55 miles north of Ottawa, is underlain by Precambrian rocks of the Grenville Series, including crystalline limestones, amphibolites

and pyroxenites, garnetiferous and sillimanitic quartz-biotite gneisses, and quartzites. The metamorphic rocks have been intruded by a large phacolithic mass of syenite and abundant thin sheets and lenses of granite pegmatite. Undeformed diabase dikes crosscut the older metamorphic series.

The areal structure is characterized by the north trend and east dip of the metamorphic rocks. Locally, intense deformation has crumpled the more competent units into tight folds which plunge northeast.

Sulfide mineralization consists of sphalerite and pyrrhotite, with lesser amounts of pyrite and a trace of galena. The zinc occurs as replacements in serpentinized and silicated marble. Mineralization appears to have been localized by sharp drag folds.

The Grenville rocks of the Gracefield-Bouchette area, and the zinc mineralization accompanying them, are similar in many respects to those of the Balmat-Edwards district in St. Lawrence County, New York.

GEOLOGY OF THE MINDAMAR MINE, STIRLING, NOVA SCOTIA

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The mineral deposit of Mindamar Metals Corporation occurs in a northeasterly striking shear zone that is subparallel to several major faults. The shear is parallel to a steeply dipping to vertical series of acidic volcanics. Rhyolite tuff in the shear is replaced by carbonate and quartz which form at least two large lenticular bodies. Within the carbonate bodies, the ore shoots, which range in grade from 7 to 20 per cent combined zinc, lead, and copper, lie along several steep veins. The position of the ore bodies within the veins is determined by several factors of which the most apparent is the presence of inclusions of unreplaced rhyolite tuff adjacent to the veins.

The workings of the previous operators are in a carbonate body 1000 feet long and up to 150 feet wide. Surface drilling has revealed an additional ore-bearing carbonate body along strike to the north and ore-grade materials, as yet undefined in outline, to the south.

METHOD FOR COMPUTING DEPARTURES FROM PRESENT MEAN ANNUAL FREE-AIR TEMPERATURE DURING QUATERNARY GLACIAL AND SOIL-FORMING MAXIMA IN THE ROCKY MOUNTAIN REGION*

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Assuming that past free-air temperature gradients paralleled the present gradient, departures from present mean annual temperature in Quaternary time may be computed.

For glacial maxima: (1) Consider the altitude of the mean July freezing isotherm to represent present regional snow line, and the altitude of a projected lower limit of ice caps to represent a regional snow line relict from the 1860 ± glacial maximum. Their difference in altitude times the local temperature lapse rate equals the rise in mean July temperature since 1860 ±. (2) Assume a constant free-air temperature at the average altitude of terminal moraines of each glacial maximum. Then, the difference between the average altitude of moraines of the 1860 ± maximum and that of moraines of any older maximum multiplied by the lapse rate, plus the rise since 1860 ±, equals, when converted to mean annual temperature, the departure from present mean annual temperature for that maximum.

For soil-forming maxima: (1) Assume that mean annual temperature at the average altitude of the Pedalfer-Pedocal soil change was the same for each soil-forming maxima, including the modern soil. Then, the difference in altitude between this change in an interstadial soil and in the modern soil multiplied by the lapse rate equals their difference in mean annual temperature.

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Computed departures from present mean annual free-air temperature for glacial and soil-forming maxima in the La Sal Mountains, southeastern Utah, are: Illinoian, −10°F.; Sangamon, +12°F.; Iowan, −7°F.; Tazewell, −5.8°F.; "Brady", +9.6°F.; Cary, −4.7°F.; Mankato, −3.4°F.; altithermal, +5.8°F.; Temple Lake, −2.8°F.; unnamed soil maximum, +2.8°F.; 1740–1860, −2.2°F.

STUDIES OF CRYSTAL FABRICS AND STRUCTURES IN GLACIERS

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Optical orientations of approximately 5000 ice crystals were determined on the Emmons, Malaspina, and Saskatchewan glaciers, by means of a 6-inch universal stage mounted between crossed polaroid sheets. The optic axes, when plotted on a Schmidt equal-area projection, show consistent patterns which appear to be related to the foliation in the ice. The patterns usually feature four strong maxima at the corners of diamond-shaped quadrangles.

Two possible mechanisms for producing common orientation of crystals in glacier ice seem plausible. One is "instantaneous recrystallization" by means of which the atoms in a lattice become energized under stress and rearrange themselves into more comfortable positions. The other is the growth of crystals favorable to deformation on glide planes at the expense of those unfavorably oriented for gliding; the latter consequently become strained and develop higher free energy.

From the study of fabric patterns in glaciers it seems likely that the crystals are oriented in such a way as to allow gliding either on two glide planes other than the well-known basal plane, or on the basal glide plane with the pattern later being changed by recrystallization, possibly by an ordered response within the crystals to the relaxation of stresses.

It is postulated that "solid flow" occurs in ice by deformation on glide planes and continuous recrystallization with migration of grain boundaries as local stresses on each crystal slowly change. The preferred orientation of crystals is probably developed by growth of crystals favorably oriented for gliding.

LIQUID IMMISCIBILITY IN THE SYSTEM K_2O-FeO-Al_2O_3-SiO_2

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Within the tetrahedron representing this system there are two separate volumes in which any point represents two immiscible liquids in equilibrium with a crystalline phase. One of these volumes lies along the FeO-SiO_2 edge and represents the extension into the quaternary of the well-known high-temperature immiscibility existing in the binary system FeO-SiO_2. The other volume lies entirely within the tetrahedron and is roughly ellipsoidal, flattened parallel to and approximately astride the 1:1 K_2O:Al_2O_3 mol ratio plane, with its longest axis subparallel to the FeO-SiO_2 edge. The compositional limits are roughly 8–52 wt. per cent FeO and 5–16 wt. per cent of the sum of K_2O plus Al_2O_3; the closest portion of the immiscibility volume to either of the adjacent limiting ternary systems K_2O-FeO-SiO_2 or FeO-Al_2O_3-SiO_2 contains about 2 per cent of the fourth component in each case. The divariant equilibrium surface between the phase volumes for fayalite and silica cuts through this immiscibility volume, resulting in rather novel crystallization histories for some compositions. The formation and crystallization of these immiscible liquids with decreasing temperature will be illustrated with a series of Kodachrome photomicrographs.

RELATIONSHIP OF MINERALOGY AND GEOMORPHOLOGY AT THE LINDENMEIER SITE IN COLORADO

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Bryan and Ray have described the geology of the Lindenmeier Site in Colorado. The object of the present paper is to integrate geomorphic and mineralogic data so as to determine the history of Lindenmeier Valley from the time of Folsom Man to the present.

The culture horizon containing the artifacts of Folsom Man is exposed in the wall of an earth canyon in Lindenmeier Valley in northern Larimer County, Colorado. Geomorphological evidence indicates that this rounded valley was carved out of Miocene Arikaree and Oligocene Brule by an east-flowing Pleistocene stream. When occupied by Folsom Man some 10,000 years ago, this valley appears to have been a wet meadow. Later, erosion products were deposited, followed probably by soil development. Repetitions left the culture horizon buried to depths up to 14 feet below the present valley floor. Later, a south-flowing stream ate headward to capture the upper drainage of Lindenmeier Valley and cut an earth canyon through the series of depositions, the Folsom horizon, and the underlying Brule.

X-ray diffraction studies of size particles under 20/^{u} indicate mineralogical differences in the profile. This may be attributed to environmental changes since Folsom Man. Further study will try to isolate the cause.

PRE-MIDDLE ORDOVICIAN ROCKS IN SOUTHWESTERN ONTARIO

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In Southwestern Ontario, a thin series of sediments is generally present between the base of the Trenton-Black River group of Middle Ordovician age and the top of the Precambrian. These rocks underlie an area of about 25,000 square miles, and their character is known principally from the samples and records of about 125 wells drilled in this area. Some exposures are present in the eastern end of the area and along the edge of the Precambrian Shield. The rocks referred to range in thickness from a few feet to a maximum of 185 feet and in character from an arkose to sandstone to sandy shale and sandy limestone or dolomite. These rocks are thickest south of Lake Huron, and in the vicinity of Lake Erie, and thinnest in the vicinity of the Algonquin arch that extends northeast-southwest across the southern portion of the province. In general, these rocks have been logged simply as "Basal Beds". Correlation with the work of Cohee on the Michigan Basin indicates that the Jacobsville, Mount Simon, and Eau Claire formations of Upper Cambrian age are represented, and some of the "Basal Beds" may be of Lower Ordovician age.

One small commercial gas pool has been discovered in Kent County, Ontario, in a sandstone believed to be the equivalent of the Mount Simon sandstone of Upper Cambrian age. Good showings of gas and oil have been obtained in these rocks in several wells at widely separated localities throughout the area.

STRUCTURE OF MONTMORILLONITE IN RELATION TO THE PHYSICAL PROPERTIES OF BENTONITES

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Properties of bentonites vary with the nature of the montmorillonite mineral and are dependent upon the proportion of exchangeable Na^{+} and Ca^{++} ions as well as types of isomorphous substitu-

tions, which, in turn, may be partially related to weathering and near-surface alterations in the bentonite deposit.

Theoretical intensity calculations were made for montmorillonite using a multiplicity factor for three possible phase shifts. X-ray analyses and theoretical calculations show that naturally occurring, air-dried bentonites contain "intimate mixtures" of three kinds of montmorillonite. One kind has two molecular layers of water, the second only one molecular layer of water, and the third no water at all adsorbed on the layers. "Double water layer particles" contain Ca^{++} as the exchangeable base; "single water layer particles" contain Na^{+} as the exchangeable base; and "zero water layer particles" are probably electrostatically neutral.

Drilling-mud yield values of bentonite samples are correlated with data obtained from the (001) diffraction lines. Best yield values come from bentonite samples with d (001) "d" value between 12.85 Å and 12.5 Å and with asymmetry values between .4 and .8. Samples with symmetrical (001) peaks are very pure in one component and show poor yields. A certain amount of exchangeable Ca^{++} is needed in a clay-water system to produce a good drilling mud because a few "double water layer particles" create enough disorder in the system to allow dispersion to take place more easily.

PEGMATITIC LITHIUM DEPOSITS OF CANADA

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Pegmatitic lithium deposits of interest in Canada occur in the Yellowknife-Beaulieu region, Northwest Territories; in the Cat Lake-Winnipeg River region and the East Braintree and Herb Lake districts, Manitoba; and in the Preissac-Lacorne region, Quebec.

The pegmatites are heterogeneous, lithium-rich, granitic pegmatites in which zones are by far the most important structural units. These pegmatites are marginal and exterior pegmatites occurring in middle- to high-grade metamorphic rocks and intrusive rocks, and related spatially, and possibly genetically, to granites containing 20 to 40 per cent potash feldspar and 20 to 40 per cent albite or oligoclase. In two of the districts, there is a regional zonation of granitic pegmatites about bodies of granite with the lithium-rich pegmatites occurring farthest from the granite. In some of the deposits, greatly elongated spodumene crystals are orientated parallel to one another.

Lithium minerals found in the pegmatites include spodumene, amblygonite, lepidolite, zinnwaldite, a variety of other lithium-bearing micas, lithiophilite, and petalite, of which spodumene is by far the most important. In most of the deposits, the spodumene is too fine-grained to be hand-cobbed.

Although there is no production of lithium minerals in Canada at present, several deposits have been diamond drilled, and extensive milling and metallurgical tests have been made on spodumene-bearing pegmatite by the Mines Branch, Ottawa, and other agencies. Considerable tonnages of pegmatite containing from 10 to 30 per cent spodumene are inferred, but the deposits are not being developed because of uncertainties concerning the market for lithium products in Canada and because of the transportation factor.

SYNTHESIS, STABILITY, AND PROPERTIES OF LAYER SILICATE STRUCTURES. I. SERPENTINE-KAOLINITE FAMILY

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Minerals with the serpentine structure have been prepared from the following compositions: $Mg_6Si_4O_{10}(OH)_8$, $Mg_4Al \cdot AlSi_4O_{10}(OH)_8$, $Mg_6Ge_4O_{10}(OH)_8$, $Ni_6Ge_4O_{10}(OH)_8$, and $Ni_6Si_4O_{10}(OH)_8$. The appropriate compositions in the following systems do not yield any serpentine (or 1:1 layer) structure: ZnO-SiO_2, CoO-SiO_2, MnO-SiO_2, Ga_2O_3-SiO_2, MnO-GeO_2, and Ga_2O_3-GeO_2. A comparison of the morphologies of the serpentine minerals formed supports the thesis that in structures of this type a "misfit" between the layers is the basic cause for the formation of cylindrical crystals. Other

data show the secondary importance of the presence of foreign ions, temperature of formation, and duration of run in conditioning this basic requirement.

A large number of other new phases has also been synthesized, including talc structures from the systems MgO-GeO_2, NiO-GeO_2, and NiO-SiO_2, an anthophyllite from the MgO-GeO_2 system, and a gallia-silica montmorillonite. A value of 8.16 per cent has been determined for the volume expansion accompanying the spinel-olivine structure inversion occurring at 1005°C in Mg_2GeO_4.

Phase equilibria in the systems MgO-GeO_2-H_2O and NiO-SiO_2-H_2O are presented as a set of pressure-temperature curves for the various reactions and are compared with those for MgO-SiO_2-H_2O. Comparative data for the various reactions show some unexpected results; thus the stability limits at 10,000 psi water pressure for the serpentines are as follows: (Mg-Si), 490°C; (Mg-Ge), 520°C; (Ni-Si), 530°C; (Ni-Ge), 360°C.

EROSION SURFACES OF CENTRAL AFRICAN INTERIOR PLATEAUS

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In contrast to the recognition by previous workers of three peneplains (end-Tertiary, mid-Tertiary, and Jurassic-Cretaceous) in the Ituri District, Belgian Congo, one major erosion surface, the end-Tertiary (High Ituri Plateau), is recognized. The mid-Tertiary surface is identified as erosional remnants, each of only a few hectares in distribution, standing above the end-Tertiary surface. The Jurassic or Cretaceous surface of previous workers is nonexistent.

Six Quaternary erosion surfaces are identified. The upper four occur in stepped sequence normal to major drainages in watersheds below the end-Tertiary surface. The lower two are an alluvial terrace along and the present flood plain of the major drainages. The Low Ituri Plateau (in part the Bunia-Irumu Plain) that extends westward from the vicinity of the Albert Rift Valley to the Congo Basin is probably a Quaternary erosion-surface complex and not end-Tertiary peneplain as previously recognized. Cutting of Quaternary surfaces is related to upwarping and faulting caused by Albert Rift Valley tectonic disturbances.

Similar surfaces of the Tertiary and Quaternary, some previously recognized, were observed in extensive occurrence east and west of and adjacent to the Albertine-Tanganyika Rift Valley in Uganda, Ruanda-Urundi, and the Kivu District, Belgian Congo.

COBALT-ARSENIC MINERALS ASSOCIATED WITH APLITES, AT COBALT, ONTARIO

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Minor cobalt mineralization is closely related to aplite dikes which in turn are differentiates of the Nipissing diabase sheet. Gersdorfite occurs as replacement of aplite and, in one instance, in a vug filling where the mineral succession has been albite, quartz, carbonate with metallic minerals.

The relationship of this mineralization to the main mineralization of the district is discussed. It is concluded that both are related to the differentiation of a tholeiitic magma.

STABILITY RELATIONS OF SOME MINERALS IN THE SYSTEM Na_2O-Al_2O_3-SiO_2-H_2O

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A study has been made of the synthesis of minerals in the low-soda portion of the system Na_2O-Al_2O_3-SiO_2-H_2O and of the phase equilibria relating these phases with temperature and pressure. Analcite, albite, paragonite, Na-montmorillonite, sodalite, cancrinite, nepheline, and a hydrated

nepheline phase were the minerals synthesized and studied. The maximum temperature stability of analcite has been located at 525 ± 5°C (from 500 to 20,000 psi), and the minimum temperature of formation of nepheline located at 460°C. A maximum decomposition temperature for Na-montmorillonite has been found at 450°C and for paragonite at 635°C.

PRELIMINARY REPORT ON THE SYSTEM Na_2O-MgO-SiO_2

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More than 200 separate compositions in this system have been prepared and studied by the method of quenching. So far, 8 ternary compounds have been recognized, all of which melt incongruently. Several of the new compounds are difficult to identify under the microscope from optical properties, particularly when they are present as tiny crystals which are suitable for rapid attainment of equilibrium between crystals and liquid. All of them are easy to identify by their characteristic X-ray powder patterns. A phase-equilibrium diagram shows the fields of the several primary phases and the temperatures and compositions of the ternary invariant points.

A knowledge of the crystalline phases and melting relations in this ternary system is prerequisite to studies of more complex hydrous systems which may elucidate the compositions and relationships between alkaline pyroxenes and amphiboles which are major constituents of certain alkaline rocks and minor mineral constituents of many igneous rocks.

SOME ASPECTS OF EVOLUTION AS REFLECTED BY INVERTEBRATE PALEONTOLOGY

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Since the genetic basis of evolution is not available to the paleontologist, he can rely only on a study of ontogeny. Evolution then is produced by a creative alteration of ontogeny. Theoretically every stage of individual development can be changed. If the alteration concerns only the very last stages of ontogeny, the phylogenetic results are very slight. This is the classic type of palingenetic recapitulation. If, however, the ontogenetic development in very early stages is led into an entirely new direction, different from that of the ancestor, immense phylogenetic effects may result. The fundamental structural plan then may be transformed, and a new type of organization originates, provided that such a basically changed animal can mate and survive.

Several stems of invertebrates—*e.g.*, the Madreporaria, Cephalopoda, and Graptolithina—offer good opportunities for a study of ontogeny or astogeny and of their bearing on the problem of phylogeny. A number of such examples will be analyzed, and some remarks on the time rates of evolution and, if time allows, also on the first steps of evolution will be included.

NOTES ON THE SILICA PROBLEM OF THE BEDROCK ORE DEPOSITS

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The problem of the source of the silica found as quartz, silicification, and silication is a basic one in the genesis of ore deposits. In the bedrock environment does silica originate and move for distances measured in thousands of feet or even in miles, or is place of origin and migration usually limited to tens or rarely several hundreds of feet?

On the answer to this question may importantly depend the final determination of the character of the ore transporting and depositing fluids. Should it be proved that most silica is limited in its

distance of migration, current ideas of differentiation of a magma toward the quartz vein and epigenetic silicate deposits may be challenged.

POLYMORPHISM IN ONE DIMENSION

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Lattices of layers of nets of equilateral triangles stacked with the nodes of each net above the centers of the triangles of the net below form an infinite set. Layers are distinguished by their immediate environments as cubic (c) and hexagonal (h). The zinc sulfide structures are examples. An admissible lattice as defined above is described by a linear series as: hcchc. . . To remove one layer (h) requires energy V_1; to remove one layer (c) requires energy V_2. At equilibrium, V, $V = V_2 - V_1$, is related to the absolute temperature and the number of layers of each type; $n_h/n_c = f(\exp -V/kT)$. For every value n_h/n_c, there is a subset of admissible lattices. Each member of the subset is distinguished by a unique value of a parameter σ; $\sigma = [n_{pq} - (n_{pp} + n_{qq})]/[n_{pq} + (n_{pp} + n_{qq})]$; p and q, $q = p - 1$, are the two possible distances from h to h in a series, n_{pq} is the number of contacts of blocks of layers of unlike distance, and n_{pp} and n_{qq} are the numbers of contacts of like blocks. If v_{pq}, v_{pp}, and v_{qq} are the energies associated with each kind of contact, $v = \frac{1}{2}(v_{pp} + v_{qq}) - v_{pq}$; v is unit energy of change of σ, $\sigma = f(\exp -v/kT)$. Admissible lattices fill equal volumes; therefore no volume discontinuities accompany polymorphism in the admissible set. Since no latent heats are observed, these transitions must be of higher order than first.

SOIL MECHANICS STUDIES FOR THE TORONTO SUBWAY

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Accurate knowledge of the physical and mechanical properties of the soil encountered in all excavation work for the Toronto subway was an essential part of construction control. The geological importance of the Toronto interglacial deposits contributed to the research significance of these soil studies which were therefore carried out jointly by the Toronto Transportation Commission and the National Research Council. A detailed profile of all soils exposed during excavation was obtained. Soil samples were obtained regularly and have been placed in permanent storage for future use and reference. Standard tests were made on selected samples. Effective correlation with local geology was maintained through a small Advisory Committee meeting at the University of Toronto.

PALEOSOLS OF THE TERTIARY OF THE GREAT PLAINS

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The correlation of many continental Tertiary deposits in the Great Plains is difficult due to the variation in lithology in the separate basins of sedimentation. Certain paleosols, especially those in Oligocene and Miocene deposits, appear to have regional distributions in the Colorado-Nebraska-South Dakota-Wyoming area and therefore are proving of great value in stratigraphic correlations.

Preliminary studies show that major faunal breaks coincide with important buried soil zones, which indicates that these paleosols actually represent unconformities. The major soils were developed on old land surfaces where deposition was practically at a stand-still for long periods of time.

The Tertiary paleosols commonly erode out as benches or ledges. In the mature soils vertebrate fossils are absent due to leaching, although in some instances fragments of bones and teeth remain in the lower horizons of the profiles. Limy concretions also are noted in the lower portions of the soil

zones. Occasionally the concretions contain fossils. The buried soils have profiles similar to those which appear in the Pleistocene deposits of the Great Plains. Compaction, however, appears to have greatly reduced the original thickness of the Tertiary soils.

EFFECT OF DIFFUSION ON THE NATURAL ISOTOPIC ABUNDANCE RATIOS

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Some processes of formation and alteration of rocks may have altered the isotopic abundance ratios of the elements in the earth's crust. Although exchange reactions have been used to explain these variations to a great extent, it would appear that isotopic fractionation due to a diffusion process might also explain, at least in part, some of the observed data. The degree of fractionation which can be expected from diffusion is shown from a theoretical study of solid-state and solute diffusion processes. Solid-state diffusion across a boundary or within a crystal can account for a fractionation of several per cent under certain high-temperature conditions, but under the more usual geological conditions diffusion will cause a fractionation of about 1 per cent or less. Solute diffusion can account for fractionation of about the same order of magnitude. These theoretical results are in qualitative agreement with experimental data in a number of cases.

These studies also show that special sampling precautions should be taken for isotopic-abundance measurements which ultimately will be used to interpret geological processes or age measurements; very small crystals or material leached from crystals might display isotopic abundances which have been altered by diffusion processes.

TRACE-ELEMENT BEHAVIOR IN REGIONAL METAMORPHISM

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Sixty-three rocks of the pelitic Devonian Littleton formation of New Hampshire have been analyzed spectrographically for trace elements. The samples represent all grades of metamorphism from shales to sillimanite schists and gneisses. The average concentrations and standard deviations are as follows (in ppm): Ga, 19, 6.3; Cr, 110, 33; V, 120, 39; Li, 110, 104; Ni, 64, 26; Co, 18, 6.6; Cu, 18, 18; Sc, 14, 7.4; Zr, 200, 73; Y, 45, 20; Sr, 710, 310; Pb, 24, 12. In addition, Be, Mo, Sn, La, Ag were sought but were usually below the sensitivity limits of 30, 10, 20, 100, 1 ppm, respectively. Ba almost always exceeds 1000 ppm.

Figures for individual analyses were grouped according to low, medium, or high grade of metamorphism. Statistical tests show a rather wide range in original composition, which suggests that it is unwise to deduce composition changes from a few analyses. Consideration of the averages, however, shows that the concentration of most elements remained constant during regional metamorphism. Ni and Cu show a slight decrease, and Li and Pb a well-defined increase of the order of 100 per cent accompanying the metamorphism. This increase is a metasomatism at the trace-element level which probably accompanies the potash metasomatism encountered by Billings in the same formation.

METHODS OF RECOGNIZING SHALLOW-WATER MARINE ENVIRONMENTS

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The first 2½ years of operation of the American Petroleum Institute Sedimentation program along the Gulf Coast has produced several innovations in methods of determining sediment environment. Variations in the composition and relative bulk of sievings of the coarse fraction of sediments have

proved particularly effective in distinguishing environments. Assemblages of Foraminifera and of mollusks are almost equally useful. Important clues are afforded by (1) the ratios of sand, silt, and clay (expressed in triangular diagrams), (2) three-dimensional plots of statistical parameters of particle sizes, (3) assemblages of Ostracoda, which appear to be much affected by variations in salinity, (4) ratios of clay minerals, which may also be related to salinity, (5) variations in organic constituents of the sediments, and (6) pollen content and distribution in the sediments.

Fourteen environments have been recognized along the Texas coast. In a test of the effectiveness of the methods employed, the environments represented by 10 samples, the locations of which were unknown, were correctly identified. The methods have also proven instructive in evaluating the environments of samples from shallow wells along the Gulf coast. It seems likely that old, deeply buried formations deposited under similar conditions can be determined in much the same way.

POTASSIUM ARGON STUDIES AT THE UNIVERSITY OF TORONTO—A PROGRESS REPORT

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In 1951–1952 the University of Toronto began studies of the radiogenic argon content of potassium minerals in order to obtain a value for the branching ratio of potassium 40, and to investigate the possibility of geological age determinations based on the radioactive decay of potassium. Preliminary results of these studies were sufficiently promising that the project was continued and expanded in the following year. Measurements of the potassium and radiogenic argon content of a number of potassium feldspars differing in age by as much as a factor of five were found to be consistent with a branching ratio of $0.060 \pm .006$.

Two new argon measuring apparatuses have been built, and the number of research workers has been increased. Present indications are that satisfactory age determinations can be made from argon and potassium measurements in feldspars and micas.

MID-PALEOZOIC POSITIVE ELEMENT IN SOUTH-CENTRAL IDAHO

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Thicknesses of Middle Paleozoic rocks in south-central Idaho north of the Snake River plain are relatively consistent, with about 4000 feet of carbonates intervening between the Middle (?) Ordovician Kinnikinic sandstone and the base of the Mississippian Milligen argillites. Normally, approximately 600 feet is referable to the Upper Ordovician Fish Haven formation, about 1300 feet to the Silurian Laketown dolomite, and an average of 2100 feet to the Devonian Jefferson and Three Forks formations. These thicknesses are of the same order of magnitude as those encountered in equivalent strata in southeastern Idaho and adjoining areas of Utah and Nevada.

Excellent exposures near the south end of the Lemhi Range in Butte County, Idaho, reveal an anomalous departure from regional thickness trends. Here the succession between the Kinnikinic and Milligen formations is about 500 feet thick, no Silurian beds are identifiable, and the Devonian Jefferson rests with marked disconformity on an eroded remnant of Ordovician Fish Haven strata. No similar changes in thickness are displayed by pre-Upper Ordovician or post-Devonian rocks.

Stratigraphic relationships involved in the Lemhi Range anomaly duplicate those which have been observed in Montana, Wyoming, and elsewhere on the North American craton where pre-Middle Devonian positive elements, accompanied by stripping of earlier Paleozoic rocks and thinning of the Devonian section, are common features. A similar duplication of relationships is noted in the pre-Middle Ordovician history of this Idaho area, thus confirming the general cratonic, rather than orthogeosynclinal, behavior of the area.

VARIATION OF LOW-TEMPERATURE DECREPITATION OF QUARTZ FROM THE NO. 6 VEIN OF THE LAMAQUE GOLD MINE, QUEBEC

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The No. 6 vein of the Lamaque mine is one of a series of quartz veins in reverse faults which cut across the hanging wall of an intrusive pipe. Quartz from this and other veins in the mine has a low-temperature stage of decrepitation. Qualitatively, the relative amount of this decrepitation increases approaching high-grade gold sections. Quantitatively, the temperature of beginning of this stage of decrepitation can be contoured in the plane of the No. 6 vein and is related to its structure.

CONFERENCES AT CRYSTAL CLIFFS, NOVA SCOTIA, ON THE ORIGIN AND CONSTITUTION OF COAL

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Three international conferences on minerals of interest to Nova Scotia have been sponsored by the Provincial Department of Mines and the Nova Scotia Research Foundation. The 1950 and 1952 conferences concerned the origin and constitution of coal, covering particular aspects of coal geology and stratigraphy, petrographic nomenclature and applications to coal, micropaleobotany of fossil spores, vacuum differential analysis, and the chemistry of coal and its formation. Speakers have included eminent scientists from North America, Europe, and Asia. Approximately 50 delegates attended each conference.

These meetings were held at Crystal Cliffs, near Antigonish, Nova Scotia, in the Nova Scotia Centre for Geological Sciences. The success of the sessions is attested by the large number of requests for invitations to future conferences and has been attributed to the relaxed atmosphere which favors informal discussion.

The proceedings of the first coal conference have been published by the sponsors, and the proceedings of the second conference are now in press.

PERIGLACIAL FROST WEDGING IN THE "ROCK CITIES" OF SOUTHWESTERN NEW YORK

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The "rock cities" near Olean and Salamanca, New York, consist of large blocks of massive conglomerate, ranging up to about 75 feet in length, separated by interconnecting passages along widened joint planes. The passages range up to several feet in width, and upwards of 10 feet in depth. Their walls are comparatively straight and approximately parallel, and follow a rectangular to angulate pattern. Adjoining the parent ledges, the blocks show no departure from bedrock either in dip or in level, but farther outward they display varying degrees of tilting and downward movement, grading into landlside masses. At present, the blocks appear to be immobile and undergoing gradual disintegration in place.

The enlargement of openings along joint planes without tilting or deleveling indicates a force acting only in a horizontal direction. Frost wedging is the one agency available to exert such a force to such a degree, and is believed to have pushed the blocks outward to the point at which gravitational forces introduced downward movement with accompanying disturbance. Conditions are no longer favorable for such processes, but must have been optimum during Wisconsin time, when the ice front at successive times lay near by to the north. The "rock cities" are thus interpreted as a hitherto unrecognized species of periglacial phenomena.

SODIC PLAGIOCLASES: (A) LATTICE PARAMETERS OF THE NATURAL HIGH- AND LOW-TEMPERATURE SERIES AND OF SYNTHETIC CRYSTALS, AND (B) REVISED DETERMINATIVE CHARTS FOR THE NATURAL LOW-TEMPERATURE SERIES

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Natural low-temperature sodic plagioclases are converted into the high-temperature form by prolonged heating near the melting point. Synthetic sodic plagioclases have been crystallized only in the high-temperature form. Accurate measurements of the six (triclinic) lattice parameters have been made on the Philips powder spectrometer of all three types of material from An_0 to An_{36} using a method similar to that of Donnay and Donnay on the synthetic alkali feldspars. A matrix method giving a least-squares solution for the lattice parameters was used.

The lattice parameters (especially γ^*) of the low-temperature sodic feldspars vary considerably with composition, thus providing a sensitive method for determining composition by X rays (sensitivity $\sim 0.5\%$ An). For the high-temperature sodic plagioclases only β^* varies appreciably with composition. This parameter is sensitive to a change of 3% An. The difference between the lattice parameters of the two series decreases rapidly as the An content increases to An_{18}.

A revised determinative chart for the low-temperature sodic plagioclases, using the angle between the (131) and ($1\bar{3}1$) reflections, has been prepared. Poor resolution of the ($1\bar{3}1$) reflection for compositions in the vicinity of An_7 seriously reduced the precision of the measurement. The angle between ($24\bar{1}$) and ($\bar{1}32$) is almost as sensitive to differences of composition, however, and has the further advantage of uniformly good resolution over the entire range. A determinative chart has therefore been prepared for these reflections.

THEORETICAL AND X-RAY STUDY OF THE MICA POLYMORPHS

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The two factors which allow polymorphism in the micas are: (1) the pseudohexagonal rings of oxygen atoms around the potassium atoms which link the layers together, and (2) the staggering of the two silicon sheets which form each layer. There are four possible ways of stacking two adjacent layers. A simple way of depicting the stacking is to give only the positions of the potassium atoms, for the complete structure can be built from this knowledge. Completely random stacking gives a one-layer, monoclinic, disordered structure (1Md). With only one stacking fault in an ordered sequence twin crystals are produced. For ordered stacking an infinity of structures can be built, but the simpler ones are 1M, 2M, 2O (Orthorhombic), 6M, 3T (Trigonal) and 6H (Hexagonal). The theoretical structures have been found in nature except for the 2O and 6H. Random arrangements of blocks of ordered layers give mixed layer structures.

Interaxial angles measured on a precession camera agree within the experimental error ($\pm 5'$) with the values for exact geometry for a 1M mahadevite, 2M muscovite (USNM 96460), 3T muscovite from Sultan Basin, Wash., and a 3T phlogopite (USNM R4463). Although bending and absorption make intensity comparisons uncertain, those intensities observed were always consistent with exact symmetry. The same Sultan Basin material had been previously described as 3M on the basis of a finite 2V and an apparent lack of symmetry between equivalent diffuse streaks.

A new twin plane (001) was found in a 1M mahadevite crystal close to eastonite in composition. The (001) twin as well as the previously described [110] twin is demonstrated theoretically. A re-examination of a six-layer, triclinic biotite of Hendricks and Jefferson indicates that this is a 2M mica described on different axes.

OCCURRENCE OF ALUNITE AND PYROPHYLLITE IN PUERTO RICO

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An alunite-pyrophyllite deposit between the towns of Comerio and Aguas Buenas approximately 20 miles southwest of San Juan, Puerto Rico, has been mapped and studied in detail. The work is being carried on co-operatively by the U. S. Geological Survey and the Puerto Rico Economic Development Administration. The area mapped embraces about 12 square miles, but the principal deposit is limited to an area about 4 miles long and a mile wide along the crest and part way down the flanks of east-west trending Cerro La Tiza Mountain. The alunite is represented principally by finely banded alunite-quartz boulders whose relationship to their source is not definitely understood. Probably some of the boulders, especially the larger ones near the crest, are the result of local weathering and have not moved far from their place of origin. The flanks of the mountain below the deposit are composed of deeply weathered greenish-brown volcanic agglomerates most probably of Late Cretaceous age.

Pyrophyllite occurs in foliated outcrops, some as much as 70 feet wide. Small patchy bodies of kaolin group minerals, sericite, and alunitic clays occur in exposures along small roads and foot trails through a heavy cover of foliage. Preliminary chemical analyses show that the alunite contains about 6 per cent K_2O and 2 per cent Na_2O.

The deposit is believed to be of hydrothermal origin, the solutions having come from quartz diorite batholiths of Eocene age south and southeast of the deposit. The hydrothermal solutions are believed to have come up along a general east-west trending line of weakness. Other smaller deposits of a similar nature have been found at intervals as far as 25 miles eastward along this trend and are being studied.

MINERALIZATION OF THE IRWIN DISTRICT, GUNNISON COUNTY, COLORADO

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The Irwin area is broken by a large number of faults that have been mineralized to various degrees. The fractures postdate the emplacement of most of the laccoliths, sills, and dikes of the region. The gaping nature of the fractures as well as the diversity of their strikes indicate a tensional origin related to broad warping. Post-mineral slippage has modified the ore texture and also accounts for most of the displacement along the faults.

The region has undergone two distinct types of mineralization. The western part of the area, including the Forest Queen mine, is characterized by arsenopyrite, proustite, sphalerite, and gold. The eastern part of the area is distinctive for its pyrite, galena, sphalerite, and chalcopyrite. Multiple waves as well as multiple centers of mineralization are indicated.

Wall-rock alteration extends up to 20 feet from the veins. Silicification, sericitization, and epidotization are noted.

COMPARISON OF MEGASCOPIC AND MICROSCOPIC EXAMINATIONS OF COAL

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Several columns of coal, previously described microscopically by means of transmitted light, were studied megascopically with the aid of a light reflected on the polished surface of the coal. The coal was prepared in the same manner that a column of coal is prepared for microscopic study by reflected light—the column was divided into blocks, ground, and polished.

The objective of the study was to determine whether or not a dull band of coal when studied megascopically corresponded to the microscopic splint or durain and, likewise, whether or not bright bands corresponded with the microscopically bright coal. It was recognized that a certain degree of transition should occur between the bright and dull bands. Such transitions were observed megascopically, and an attempt was made to correlate such areas with semi-splint and claro-durain.

Mineral matter plays an important role in the dullness or brightness of coal, and because of the abundance of this impurity, in many cases, the luster of an otherwise bright band is partially lost. In such cases, the correlation between megascopic and microscopic analyses, in terms of bright and dull coal, is non-existent. However, there are cases, in which mineral matter is not present, where megascopic dullness does not always correspond with microscopic luster. It is therefore suggested that the dullness or brightness of a coal may not be determined by one microscopic maceral, such as opaque matter or vitrinite, but perhaps by an association of macerals, as well as by the amount of ash in the coal.

PROGRESS IN AIRBORNE RADIOACTIVITY SURVEYING

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Further development of airborne radioactivity surveying by the U. S. Geological Survey and the Oak Ridge National Laboratory during the last 2 years has improved greatly the technique both for prospecting and for geologic reconnaissance. In prospecting for new occurrences of uranium and thorium, local concentrations of radioactive materials of possible economic significance can be detected satisfactorily 500 feet above the ground. For maximum efficiency when using multi-engine aircraft a unit area of at least 50 square miles should be surveyed. Selection of areas for survey should be based on the best geologic inferences drawn from general knowledge of where uranium and thorium are most likely to occur. Promising results have been obtained in areas so selected.

Airborne surveys in North Carolina, Florida, California, and Arizona show that radiation intensity is related to the areal distribution of various rock types; thus such surveys provide a reconnaissance technique for delineating major geologic features with rapidity and at low cost. In geologic reconnaissance, rock types can be distinguished both where rock outcrops occur and where residual soils blanket the bedrock.

Empirical measurements of gamma radiation intensity have been made at various distances over point sources of different gamma radiation energies and over simulated ore outcrops; these data accord with and confirm theoretical analyses of the absorption and scattering of gamma radiation in various media and geometric configurations.

ORDOVICIAN-SILURIAN BOUNDARY IN MANITOBA*

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The Stonewall formation has been placed at the base of the Interlake group (Silurian) and overlies the Stony Mountain formation of Richmond age. The formation can be traced from its type section north of Winnipeg northwestward to the Saskatchewan border. It is more clastic than the dolomites of the rest of the Interlake group. At the type section of the Stonewall formation the presence of *Kochoceras* and *Antiplectoceras* in the lower beds supports Okulitch's correlation of them with the Upper Ordovician. The fauna of the upper beds, formerly considered of Early Silurian age, has

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Richmond affinities, and though it greatly resembles the fauna of the Stony Mountain formation has little in common with that of the overlying Interlake beds. These faunal relations exist all along the belt of outcrop. Of 28 fossils identified from the Stonewall formation 22 favor a Richmond age, and only 3 occur in the younger rocks of the Interlake group. The Stonewall formation should therefore be removed from the Interlake group and the Ordovician-Silurian boundary placed above it.

The Interlake dolomites overlying the Stonewall formation contain *Virgiana decussata*. The *Virgiana*-bearing formations of central North America are commonly recognized as of Clinton age. Since the Stonewall formation is Ordovician, the great faunal break above it reflects the lack of Lower Silurian sediments in Manitoba.

PELECYPODA OF THE MIDDLE EOCENE STONE CITY BEDS OF TEXAS

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The Stone City (Middle Eocene) fauna is a varied fauna of vertebrates, decapod crustaceans, cephalopods, gastropods, scaphopods, pelecypods, bryozoans, brachiopods, annelids, hexacorals, foraminifers, and ostracodes. It ranges from brackish to normal saline, depending on bed and location, and is probably lagoonal or estuarine. It is less rich in species, by 28 per cent, than the succeeding Cook Mountain fauna, which is chiefly normal saline and open-sea neritic. The Stone City fauna contains 32 species of pelecypods, of which 17 are new species. These species belong to 22 genera and 30 subgenera, of which one genus and two subgenera are new. The paper describes all pelecypods of this fauna and several species from adjoining formations and includes many nomenclatorial, taxonomic, stratigraphic, and evolutionary data concerning the various genera, subgenera, and species present.

CLASSIFICATION OF AMERICAN DUCK-BILLED DINOSAURS

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The better-known members of the Hadrosauridae appear to fall naturally into two subfamilies, Hadrosaurinae and Lambeosaurinae. *Saurolophus* is fundamentally a flat-headed form. In *Chenesaurus*, as in other hooded forms, modified premaxillae and nasals surround elongated, looped narial passages, and, in all, the same bones serve the same function. The number of tooth rows is not dependable because of the great variation with age of the individual.

ISOTOPIC COMPOSITION OF LEAD IN LEAD MINERALS FROM THE COLORADO PLATEAUS

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Approximately 45 specimens of lead minerals have been collected from the Colorado Plateaus and adjacent areas. The isotopic composition of the lead in these minerals has been determined. This work is part of a detailed study of the lead-uranium ages of the uranium ores from the upper Triassic and upper Jurassic rocks of the plateaus.

The Pb^{206} content of essentially uranium- and thorium-free lead minerals ranges from approximately 24 to 60 per cent. The absence of thorium from the plateaus sediments is reflected by the relatively constant Pb^{204}/Pb^{208} ratio. Systematic changes in the Pb^{206} and Pb^{207} contents suggest the addition of small amounts of old radiogenic lead whose age is approximately one billion years.

The systematic variations in the isotopic compositions of the lead minerals from the uranium de-

posits of the plateaus and the Tertiary deposits adjacent to the Colorado Plateaus strongly suggest a common or similar source for the original lead as well as the added radiogenic lead. The apparent relationship of the lead in the plateaus and adjacent ore deposits in upper Triassic, Upper Jurassic, and Tertiary rocks is supported by the Tertiary lead-uranium ages which have been determined for these uranium ores.

In addition to the application of the regional variation in the lead-isotope abundances to certain problems of ore deposition, the isotopic data on the Plateaus leads may also be used to evaluate the current estimates of the Pb^{207}/Pb^{206} age of the earth using ore leads. Some of the assumptions required by the Pb^{207}/Pb^{206} method do not appear to be supported by these new isotopic analyses.

MEDIAL TO LATE CENOZOIC CORRELATIONS BETWEEN EURASIA AND NORTH AMERICA

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Considerable refinement is now possible in the intercontinental correlations of Cenozoic deposits between Eurasia and North America, and new evidence from the fossil mammals (especially the beavers) allows evaluation of these as of first-, second-, and third-order reliability. Little disagreement is anticipated with regard to the primary correlations, such as is afforded by the widespread occurrence of the beavers *Dipoides* and *Anchitheriomys* on both continents in limited stratigraphic situations and faunal associations. Attention should be focused on those critical regions where continental and marine sediments intertongue, for it is there that the continental and marine standards may be checked. It is evident that clear-cut rock and faunal successions must be established wherever possible, and the West European and Great Plains (United States) standards are especially important because of their completeness. Stratigraphic terms require careful definition, and even the major Cenozoic divisions (such as those named by Lyell) have type localities.

The Pliocene-Pleistocene boundary, as well as the Tertiary epoch/series boundaries, can now be drawn rather accurately in the United States. Fossil mammals of Astian-Plaisancian and Villafranchian types are distinctive, especially in the Great Plains. Within the Pleistocene, the Cromerian (Günz-Mindel interglacial) and Yarmouthian (chiefly Kansan-Illinoian interglacial) mammals correlate. The Günz I and Günz II glaciations (double cold phases in the English Crag and other successions) would thus appear to correlate with the Nebraskan and Kansan glaciations of North America.

DIMENSIONAL ANALYSIS IN GEOMORPHOLOGY

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Dimensional analysis permits quantitative geomorphic studies to be placed on a sound geometrical and mechanical basis. Form elements of fluvially dissected landmasses are first analyzed according to dimension. Such measures as stream length, relief, length of overland flow, and perimeter have the dimension of length (L). Drainage density, texture ratio, and curvature of profile have an inverse length dimension (L^{-1}). Areal measures and volumes have the dimensions of length squared (L^2) and length cubed (L^3) respectively. Dimensionless parameters include stream-order number, azimuth, and angle of ground and channel slope. Combinations of dimensional elements produce dimensionless numbers such as stream-length ratio, basin-circularity ratio, ruggedness index, and hypsometric integral, which provide descriptive indices of the terrain irrespective of scale.

Complete geometrical similarity of landforms in two regions exists when all corresponding linear dimensions are in the same scale ratio, and all corresponding dimensionless numbers are the same. As an illustration, approximate similarity is established between small areas of mountainous terrain

in the Verdugo Hills, California, and the Great Smoky Mountains, North Carolina. Two regions may have close dimensional similarity of planimetric forms, but differ greatly in vertical dimensions (slope and relief).

Application of dimensional analysis and the Pi Theorem to erosion intensity as a function of runoff intensity, an erosion proportionality factor, relief, and drainage density yields five dimensionless groups: The Reynolds and Froude numbers, a ruggedness index, an erosion-intensity ratio, and a Horton number, which is the product of runoff intensity and the erosion proportionality factor.

SYNTHETIC ZINC SULFIDE POLYTYPE CRYSTALS

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X-ray examination of zinc sulfide crystals grown from the vapor phase show that they consist of mixed polymorphic structures in the majority of cases, regardless of their external morphology. In addition to intimate mixtures (on atomic scale) of 2- and 3-layer structures—wurtzite and zincblende (or rhombohedral, Buck and Strock)—they also show the Frondel and Palache polytypes of 4- and 6-layer structures. Crystals containing 2, 3, 4, 5, 6, 7, 8, 9 and 11 layer structures have been observed. Many crystals show very intense diffuse x-ray reflections from certain hkl zones of constant hk values, not reported for the natural polymorphs. The role of impurities in determining the structure and growth habit of the crystals has been studied.

GEOLOGICAL INVESTIGATIONS AT KEMANO, BRITISH COLUMBIA

R. A. Stuart
% Alcan, Kemano, B. C.

A 10-mile-long tunnel, at present under construction as part of the Aluminum Company of Canada power development in British Columbia, will divert to the west normally eastward-flowing water from the Tweedsmuir Park area and provide a head of approximately 2400 feet for generators in an underground powerhouse at Kemano.

This paper outlines briefly the geological studies that have been completed in the tunnel and on the surface along the route of the tunnel. Geological considerations of importance in the excavation and support of the tunnel are discussed, and items to be made the subject of further investigation are mentioned.

OSAGE DELTAIC DEPOSITS IN SOUTHWESTERN ILLINOIS*

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A tongue of Borden marine siltstone (Osage group, Lower Mississippian) 200 miles long, 60 miles wide, and 400 to 800 feet thick extends in subsurface southwestward from the main body of Indiana Borden siltstone to points only a few miles east of Osage limestone outcrops near St. Louis. Northwest of the tongue the Osage is largely crinoidal, southeast it is dark silty siliceous limestone.

The siltstone tongue includes (1) basal shale a few tens of feet thick essentially parallel to the overlying and underlying formations, (2) a main body of alternating shale and siltstone beds dipping south to west at 30 to 90 feet per mile with respect to adjacent formations, and (3) an upper set of fine-grained sandstone, siltstone, shale, and limestone layers essentially parallel to, and grading into, the overlying Warsaw formation.

Closely spaced rotary drilling with electric logging allows detailed study of 1400 square miles

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centered 50 miles east of St. Louis. Of numerous beds traced across the foreset slope only the more prominent can be followed within the compressed sections of top- and bottom-set beds. Isopachs of Borden rocks beneath each of nine beds and of intervals between these beds show the advance of the slope from northeast to southwest and shifting of areas of greatest accumulation, apparently in response to shifts in active distributaries.

This Borden tongue is a seaward extension of Lower Mississippian foreset deposits in south-central Ohio, 400 miles east of this area.

URANIUM IN THE CHATTANOOGA SHALE*

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The Upper Devonian and lower Mississippian black shales of south-central Kentucky, central Tennessee, and northern Alabama range in thickness from a feather edge to 40 feet and contain small amounts of uranium.

The origin and mineralogic association of the uranium have not been precisely determined, but fluorimetric analyses of some 150 special samples of the shale indicate:

(1) The uranium is not intimately tied to pyrite or phosphate, which are important constituents in the shale.

(2) On a small scale, the uranium is uniformly distributed, both laterally and vertically, in a given unit of essentially homogeneous black shale; regional differences in uranium content in the same unit are part of orderly trends.

(3) The amount of uranium in a lithologic unit is approximately proportional to the relative amount of organic material present.

(4) Certain "bitumen" layers are richest in uranium.

(5) The uranium content of a given time-stratigraphic unit is highest where that unit is thinnest, other factors equal.

These results, coupled with field relationships, point to a probable syngenetic organo-uranium compound thoroughly disseminated as submicroscopic specks or films attached to the individual shreds of plant material. Assuming a constant, but very small, supply of uranium in the sea water the amount of uranium chemically tied to any given surface of deposition in the shale is dependent on the relative length of time that surface was exposed on the sea bottom, and on the proportion of organic material making up that surface.

MINERALOGY OF SOME MICROFOSSILS†

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The x-ray powder diffraction technique is well suited to determining the mineralogical composition of microfossils. By this means it is possible, if the fossil consists of a fine-grained aggregate, to determine the original mineralogical constituents of the organism or the nature of the minerals that have replaced the original shell material if replacement has occurred. Most foraminifers and ostracodes are composed of such fine-grained material that it is not necessary to crush or in any manner alter the morphology of the material in order to examine it successfully by the x-ray diffraction technique. Unreplaced perforate and imperforate foraminifers are composed of calcite; agglutinated foraminifers incorporate the following minerals in their walls: calcite, aragonite, quartz, plagioclase,

* Publication authorized by the Director, U. S. Geological Survey

† Publication authorized by the Secretary, Smithsonian Institution, and the Director, U. S. Geological Survey

pyroxene, hornblende, magnetite, biotite, and glass. Foraminifers, ostracodes, pelecypods, and gastropods replaced by heulandite occur at several localities, in beds of Tertiary age. The radular elements of *Nautilus pompilius* were found to be composed of an indeterminate but possibly chitinous substance.

ORDOÑEZITE, ZINC ANTIMONATE, A NEW MINERAL FROM GUANAJUATO, MEXICO*

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Tin ores from the Santin mine, Guanajuato, Mexico, contain a new mineral having the chemical composition $ZnSb_2O_6$. The mineral is in small pale- to dark-brown crystals associated with cassiterite. It is tetragonal, $a = 4.66$, $c = 9.24$ A, space group $P4/mnm$; specific gravity = 6.64. The structure is the trirutile type, and the mineral is isostructural with tapiolite ($FeTa_2O_6$), bystromite ($MgSb_2O_6$), and many other artificial antimonates and tantalates. The name ordoñezite is proposed for the mineral after the late Ezequiel Ordoñez, outstanding Mexican geologist.

ORIGIN OF THE NATIVE SULFUR DEPOSITS OF LOUISIANA AND TEXAS FROM SULFUR AND CARBON ISOTOPE STUDIES

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Preliminary isotope studies carried out in the laboratory suggested that the native sulfur deposits of Louisiana and Texas were formed by the bacterial reduction of sulfate with which they are associated. This work has been continued, and sulfur isotope ratios have been investigated in the sulfates, sulfur, and sulfides obtained from sulfur well-core samples. Also carbon isotope ratios were measured for the associated limestone.

The native sulfur and sulfides of the core samples contain on the average 3.8 and 4.8 per cent less S^{34} respectively than the associated sulfate. These differences compare with similar differences found for sulfates and sulfur from lakes and wells in which bacterial reduction of sulfate is known to take place. This relationship between the isotopic ratios of sulfates, sulfur, and sulfides is particularly significant in view of the extensive variation in isotopic level from one sulfur well to another.

The carbon in the associated limestone is particularly low in C^{13} content, indicating that the limestone is not of the usual sedimentary origin but results from the CO_2 liberated by the sulfur-reducing bacteria and is therefore of organic origin. These results point definitely to the bacterial reduction of sulfate as the origin of Texas and Louisiana sulfur deposits.

PLEISTOCENE SILTS, STORY COUNTY, IOWA

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Deposits of silt, sandy silt, and gravelly silt, commonly associated with sand and gravelly sand, are exposed at many places in central Iowa. These silts occur in lenticular masses from a few acres to as much as a quarter of a square mile in area and from a few feet to more than 75 feet in thickness. They show little or no bedding or lamination although variations in clay, sand, or gravel content do

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produce a crude stratification which is recognizable in detailed sampling. In natural exposures the silts resemble loess, and some exposures have been so designated by previous authors.

The silts are known to be overlain by Cary till and to grade vertically and horizontally into the till. Some deposits are known to rest on Cary till, but the nature of the underlying material is not known in all instances.

The silts are characterized by a rather abundant and varied fauna. Terrestrial gastropods predominate, but aquatic forms are common and locally are abundant. Fresh-water ostracods are common and in certain units are abundant. Other forms present locally include pelecypods and other arthropods. Fossil wood and plant fragments are present locally. These silts are believed to represent local aqueous deposits which are essentially contemporaneous with the Cary till.

USE OF ISOTOPE DILUTION IN DETERMINATION OF GEOLOGIC AGE OF MINERALS

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The method of isotope dilution along with the mass spectrometer for determination of radiogenic Sr^{87} and Rb^{87} reported by Aldrich has been greatly extended so that 0.01 per cent of rubidium and 0.0001 per cent of radiogenic Sr^{87} have been estimated accurately using only 100 mg. of mineral sample.

For each age determination 0.5 μg of Sr^{90} and 0.01 μg of fission rubidium containing 70.2 per cent Rb^{87} were used. The possibility of working with such small quantities has greatly simplified chemical separation of strontium and has made separation unnecessary for rubidium. The use of Sr^{90}, a readily available fission product absent in natural strontium, makes the interpretation of the mass spectrograms simpler. The radioactivity of Sr^{90} and of its daughter isotope Y^{90} greatly facilitates chemical manipulation. Determination of ages for minerals containing many times as much normal strontium as radiogenic Sr^{87} have been carried out.

Ages are presented for one lepidolite and two biotite minerals. The ages obtained are considerably greater than those found by other methods. Since incorrect ages would result if fractionation of rubidium and strontium had occurred due to weathering, this possibility was studied by determining ages of one biotite after washing with hydrochloric acid and aqua regia. These treatments did not materially affect the value of the ages.

GEOLOGICAL ENGINEERING PROBLEMS OF FLOODS ORIGINATING IN GLACIAL LAKES OF THE PERUVIAN ANDES

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Rupture of outlets of glacial lakes in the Cordillera Blanca area of the Peruvian Andes in recent years has caused serious floods. Peak discharges of 100,000 to 200,000 second feet—5 to 10 times the usual annual peak—flow out of glacial valleys into the Santa River, the master stream of the area, causing the level of water to rise as much as 140 feet in narrow gorges. The floods carry tremendous quantities of debris and in the waning stages are moving masses of mud, sand, and rock, which eventually come to rest clogging the valley to great heights. The lakes that cause the floods are found at altitudes of 14,000 to 16,000 feet. They occupy basins behind the frontal moraines of retreating glaciers. The failure of the lake barriers is associated with overtopping of the outlet owing to rise in lake level after sudden storms or to waves produced by falling masses of ice or rock. Undermining by piping is a possible but not general cause. Control measures consist principally of lowering the lake level and construction of barriers to prevent overtopping.

DETERMINATION OF POLAR AXIAL ANGLES AND POLAR AXIAL RATIOS FROM INTERFACIAL ANGLES

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A simple method of calculation of crystallographic axial ratios and axial angles, and a simple method of determination of Miller indices from measurements of interfacial angles with the one-circle goniometer or with the contact goniometer, are especially needed by mineralogists and geologists whose principal interests are in branches of geologic science other than crystallography but who wish to make some use of crystallographic data in mineral determination.

In all crystal systems the polar axial angles are defined as the angles between the edges of a parallelepiped constructed with its edges perpendicular to the faces 100, 010, and 001, and with its body diagonal perpendicular to the face 111, and the polar axial ratios are defined as the ratios of the lengths of the edges of this parallelepiped. The edge perpendicular to the face 100 is designated p_0', the edge perpendicular to the face 010 is designated q_0', and the edge perpendicular to the face 001 is designated r_0'; the angle between q_0' and r_0' is designated λ, the angle between p_0' and r_0' is designated μ, and the angle between p_0' and q_0' is designated ν. The polar axial angle λ is thus by definition the angle between the normals to the faces 010 and 001. Likewise the polar axial angle μ is by definition the angle between the normals to the faces 100 and 001, and the polar axial angle ν is by definition the angle between the normals to the faces 100 and 010. The polar axial angles of some triclinic minerals can thus be obtained as measured interfacial angles or as the sums of measured interfacial angles.

The polar axial ratios of a triclinic crystal can be calculated by means of the equations:

$$\frac{p_0'}{r_0'} = \frac{l \sin (001 \wedge hOl)}{h \sin (100 \wedge hOl)}, \tag{1}$$

$$\frac{q_0'}{r_0'} = \frac{l \sin (001 \wedge Okl)}{k \sin (010 \wedge Okl)}, \quad \text{and} \tag{2}$$

$$\frac{p_0'}{q_0'} = \frac{k \sin (010 \wedge hkO)}{h \sin (100 \wedge hkO)}, \tag{3}$$

The polar axial ratios of some triclinic minerals can thus be obtained as the ratios of the sines of measured interfacial angles.

In the other crystal systems the calculation of the polar elements from interfacial angles is even more simple.

CONTINUITY BETWEEN HYDROUS GRANITE MAGMAS AND HYDROTHERMAL SOLUTIONS

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Some recent papers dealing with the residual solutions of crystallizing granite magmas have stressed the view that there is a hiatus between granite magmas and hydrothermal solutions. The experimental results chosen to support this theory have been carried out on synthetic mixtures and on granites having compositions only partly miscible with water (at pressures which are to be expected in the outer part of the earth's crust) and therefore support this view.

Studies on the system K_2O-Al_2O_3-SiO_2-H_2O indicate, however, that a continuous gradation from granite magma to hydrothermal solution is to be expected *in certain compositions*. In this system mixtures having compositions near the quartz-orthoclase join with an excess of alkali over the potash

to alumina ratio of orthoclase may give, on crystallizing, a liquid phase that ranges in composition from a silicate melt containing a small amount of water to a liquid consisting largely of water. Similar results are to be expected in the system Na_2O-Al_2O_3-SiO_2-H_2O. Extrapolation of these results to mixtures of K_2O-Na_2O-Al_2O_3-SiO_2-H_2O suggest that a similar gradation must obtain in compositions closely approaching those of natural granites.

Examination of 442 analyses of rhyolitic rocks in Washington's tables reveals that 21 per cent of the rhyolites contain alkalies in excess of that required to combine with the alumina to form feldspar. It is suggested that these granite liquids may, on crystallizing, give rise to liquids whose water content increases continuously until the liquid is largely water. The quantity of hydrothermal solutions developed will depend on the amount of water present in excess of that required to form hydrous minerals, and on the amount of alkalies not combined with alumina to form feldspars.

MAGMATIC ORIGIN OF A TERTIARY GRANITE FROM THE ISLAND OF SKYE, SCOTLAND

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Recent detailed study of the properties of quartz and feldspar show that both may yield information on the conditions under which they crystallized. The inversion temperature of quartz can be used as an indicator of relative temperatures of crystallization; high-temperature and low-temperature feldspars can be distinguished by determinations of composition and optic angle.

Previous investigation showed that quartz samples from a group of granites invert at higher temperatures than do quartz samples from a group of rhyolites, and it was suggested that the observed difference between "rhyolite quartz" and most "granite quartz" probably results from late-stage recrystallization of granite minerals at low temperature. A small pluton on the Island of Skye was selected for study as a type of occurrence which might yield granite which had not recrystallized completely. Quartz was separated from 25 specimens, and the inversion in every case was similar to that of quartz from rhyolites previously studied. The alkali feldspar holds up to 45 per cent albite in solid solution and has properties characteristic of sanidine which has changed partially to orthoclase cryptoperthite. The plagioclase feldspar is high-temperature oligoclase. The granite has the textural features of a granite together with the mineralogical features more commonly found in rhyolite. The evidence thus points to a magmatic origin of the granite.

BROWN COAL IN THE LABRADOR TROUGH

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Drilling operations on an ore deposit in the Labrador concession of the Iron Ore Company of Canada in 1952 brought to the surface fragments of brown coal. Three holes revealed brown coal through a thickness of several score of feet, at depths below 150 feet from the surface; in each case iron ore lay above and below the coal. Thin-section analyses have confirmed the plant nature of the organic material and show it to be of coniferous origin, probably of the family Cupressaceae. This in turn suggests an Upper Mesozoic or Tertiary age for the organic material. Its relation to the iron ore is uncertain because of the unknown structural pattern within the ore deposit; it may be folded or faulted into the iron, or it may be an exceedingly large crevasse filling. Should one of the former instances prove to be the case, evidence of late Mesozoic or Cenozoic tectonism within the Labrador Trough of the northeastern Canadian Shield is indicated.

PHACOLITH OF CHARNOCKITIC ADAMELLITE PORPHYRY AT KEIMOES, CAPE PROVINCE, SOUTH AFRICA

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The charnockitic cycle separates the earlier Kheis orogeny from the numerous pegmatites found throughout the Archean of the northwest Cape, dated at 1200 million years. The phacolith occupies 225 square miles, and similar bodies are found elsewhere in the region. Slightly earlier dikes are basaltic and contain labradorite and bronzite phenocrysts and quartzitic xenoliths. Upon emplacement the charnockitic magma contained phenocrysts of andesine and orthopyroxene, blue quartz xenocrysts, and metasedimentary xenoliths. After emplacement augite, hornblende, biotite, clear quartz, titanomagnetite, and potash-soda feldspar crystallized. The magma apparently originated by deep-seated contamination of a basaltic magma. Country rocks are psammitic metasediments with minor pelitic and cafemic intercalations, lenses of orthoamphibolite and metagabbro, and syntectonic lenses of tonalitic to granodioritic gneiss. Contacts with the charnockite are sharp when parallel to the foliation of the country rocks, and the charnockite becomes finer-grained toward such contacts. Cross-cutting contacts are gradational. Migmatitic rocks are adamellite hybrids with charnockitic textures, permeation gneisses, and mixed rocks produced by intermingling of hybrid magma and mobilized country rocks. The magma was emplaced during compression of rigid folded strata, plastically deformed during the Kheis orogeny. After emplacement compression persisted, resulting in the production of compression joints in the charnockite. Differential movements along joints produced cataclastic deformation in adjacent charnockites. Solutions ascended through the joints and altered neighboring charnockite to quartz-epidote rocks. Constituents removed in this process were concentrated below the roof of the phacolith, where the rocks were changed to syenites of pneumatolytic origin.

STRUCTURAL SETTING OF THE COEUR D'ALENE MINING DISTRICT, IDAHO-MONTANA

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The Coeur d'Alene mining district is in an intensely deformed structural knot in Precambrian metasedimentary rocks at the intersection of a northeastward-trending and a northwestward-trending structural element in the Northern Rocky Mountain province. Monzonitic and syenitic stocks, together with large folds and faults, constitute the northeastward-trending element; the Osburn fault, which is at least 150 miles long, dominates a group of folds and faults trending northwestward.

The veins are grouped in zones that trend essentially northwestward, subparallel to the Osburn fault. The district has been subjected to repeated deformation by stresses of different orientations; as a result reverse faults, strike-slip faults, and normal faults have developed.

METAMORPHISM AND GRANITIZATION IN THE EASTERN ADIRONDACKS

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In the eastern Adirondacks copious volumes of granitic gneiss have syntectonic relations to metasediments. All the rocks contain small bodies of undeformed granite, pegmatite, and aplite, which locally crosscut, but the bulk of the granite was deformed with and is concordant with the complexly folded metasediments. Alkali metasomatism was widespread. Microcline and sodic plagioclase por-

phyroblasts are common in all rocks including marbles. The metasediments are of high metamorphic rank characterized by sillimanite-biotite-garnet gneiss and pyroxene-garnet-hornblende granulite. Granite bodies have no contact-metamorphic aureoles (skarnlike mineral assemblages in Grenville calcareous rocks are ubiquitous and attributed to regional metamorphism). On the contrary retrograde effects are notable in metasediments highly involved with granite.

It is argued that the level of regional metamorphism attained in the eastern Adirondacks was such that the stable mineral assemblages in the metamorphic rocks were in equilibrium with P-T conditions at which granitic fluids were also stable, and that such fluids arose and produced both magmas and metasomatism wherever the appropriate components were present. Retrograde effects were produced by aqueous solutions released on the consolidation of granitic liquids. A contrast is drawn between this regional picture and regions where granites are surrounded by strong contact-metamorphic aureoles. Here granites represent sources of metamorphosing energy rather than products of metamorphism and must invade from a region where the energy level is higher. Harmony with the level of regional metamorphism is suggested as the limiting condition for granitization.

APPLICATIONS AND LIMITATIONS OF GEOPHYSICAL PROSPECTING IN NEW BRUNSWICK

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Employment of airborne magnetic and ground electromagnetic methods has led to the discovery of two important new ore bodies in the Bathurst area of New Brunswick. Several other geophysical methods are currently in use in New Brunswick, notably resistivity, ground magnetic, and geochemical soil testing. The part each of the five methods has played in the discovery of sulfide mineralization is noted. The applicability and limitations of each method are described particularly with reference to the problem of distinguishing sulfide mineralization, graphitic sediments (which are abundant in the area), and magnetite deposits.

The airborne magnetometer maps structure by virtue of its response to magnetite content in rocks and ores. The electrical methods map electrically conducting bodies such as sulfide mineralization and graphitic sediments. Geochemical soil testing, in the limited number of cases in which it has been applied, has been successful in separating those zones of good electrical conductivity which contain quantities of such metals as copper and zinc from those which do not contain these metals.

The ground magnetic method details the magnetic intensity pattern outlined by the aeromagnetic survey; it is of lesser importance in estimating the percentage (of magnetic minerals) in subsurface electrical conductors.

It is concluded that such generally drift-covered areas as New Brunswick must be prospected by geophysical methods. A discussion of the problems in widespread geophysical exploration in such areas concludes the article.

BIOGEOCHEMICAL INVESTIGATIONS IN EASTERN CANADA

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During the past 5 years the authors have investigated the practicability of using biogeochemical methods in prospecting for buried ore bodies in Eastern Canada.

On the basis of more than 5000 analyses, "normals" are tentatively suggested for copper and zinc in most of the more common species of trees and lesser plants including Jack Pine (*Pinus Banksiana*), Black and White Spruce (*Picea mariana* and *Picea glauca*), Tamarack (*Larix laricina*), Balsam (*Abies balsamea*), Poplar (*Populus tremuloides*), White Birch (*Betula papyrifera*), and Labrador Tea (*Ledum groenlandicum*).

The influence of underlying mineralization has been found to parallel that observed in the Pacific Northwest.

In the light of present data variations above "normal" of more than 50 per cent in copper and 30 per cent in zinc may be considered possibly anomalous, and more than 100 per cent in copper and 50 per cent in zinc probably anomalous.

The most important conclusions are that:

(1) With reasonably propitious conditions practically all trees or lesser plants are capable of reflecting buried mineralization.

(2) There is no direct relationship between the metal content either of dry plant or ash and the metal content of the underlying mineralization.

(3) With present techniques biogeochemistry can only, except under unusually favorable circumstances, yield useful results where muskeg or overburden is less than 30 feet thick.

(4) Just as geologists can point to metallogenetic provinces so the biogeochemists can outline trace-element provinces.

PARAGENESIS OF THE ZINC-LEAD-COPPER DEPOSITS AT THE MINDAMAR MINE, NOVA SCOTIA

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The mine is in Richmond County, Cape Breton Island. The ore bodies are irregular lenses within a persistent, wide, steeply dipping shear zone cutting mainly sericite schist. The schist was derived principally from siliceous siltstone of probable Middle Cambrian age.

The deposits consist of extremely fine-grained pyrite and sphalerite with minor chalcopyrite, galena, and tennantite in gangue composed mainly of dolomite, magnesite, quartz, sericite, talc, and chlorite. They were formed chiefly in the following overlapping stages:

(1) Deposition of most of the fine-grained pyrite and sphalerite by replacement of sericite schist.

(2) Deposition of most of the dolomite and magnesite and some of the quartz, partly in fractures and partly by replacement.

(3) Deposition of most of the galena, chalcopyrite, and tennantite, some of the pyrite and sphalerite both in carbonates and in fine-grained pyrite, and sphalerite-bearing ore.

Some dolomite and magnesite appear from their texture to be metacolloidal. Talc occurs chiefly as randomly oriented flakes which originated by replacement of dolomite and magnesite without recognizable change in volume.

Most of the numerous diabase dikes were intruded after deposition of carbonates and ore minerals. Several, however, were emplaced before completion of carbonate and ore deposition and have intensely carbonatized and locally mineralized margins.

Much fine-grained ore shows thin layers differing from one another in [illegible] ions of ore minerals to gangue minerals or of individual ore minerals to each other. This structure may be attributable mainly to selective replacement of relic lamination in schist and partly to replacement along closely spaced fractures.

CORRELATION OF THE PLEISTOCENE GEOLOGY AS SEEN IN THE SUBWAY WITH THAT OF THE TORONTO REGION, CANADA

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In the excavation for the Rapid Transit subway, a 25- to 50-foot section was cut for 4 miles in a north-south direction in the center of Toronto. It revealed almost every Pleistocene formation to be seen in the Toronto area.

At least three tills were exposed, the lowest of which was probably Illinoian, as it underlay the Toronto Interglacial beds, considered by the author to be Sangamon in age. The interglacial beds were represented by 2 feet of "warm climate" Don sands overlain by at least 20 feet of "cool climate" Scarborough clays. The upper surface of the interglacial beds showed marked change in relief due to erosion by the Wisconsin glacier.

A soil profile, leached to a depth of 3 feet, and preserved under the lowest Wisconsin till, established the age of fossil peaty material found in the subway to be the same as the Toronto Interglacial beds and indicated that the high land above Lake Iroquois shore line existed prior to the Wisconsin glaciation. Narrow zones of thick varved clays and a steeply inclined till veneer testified to the ponding of glacial waters against this upland and its subsequent overriding by the glacier.

Varved clays and stratified sands overlying the lower Wisconsin till suggested a considerable time break, correlated probably with the Two Creek interval.

At least one upper Wisconsin till overlay the interstage sands, but it was removed in places by subsequent glacial lake and stream erosion.

"TACONIC ALLOCHTHONE" IN THE COPAKE AREA, NEW YORK

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The Copake quadrangle, in eastern New York, lies in an area previously considered part of the "Taconic Allochthone". In the eastern part, the rocks consist mainly of carbonates and sandstones, and in the western part, they are almost entirely shales with some quartzites and calcareous grits. The Berkshire Hills, underlain by quartz-chlorite schist, appear just at the eastern edge of the quadrangle. Mapping has produced no evidence to support the "nappe" hypothesis, which is based on the facies contrast between the shales and carbonates. The structure is of an imbricate nature, consisting of a number of reverse-faulted blocks, affecting both the shales and the carbonate rocks.

The shales have been separated into two major groups—the characteristically black shale of Trenton age, and a typically gray shale series, considered Upper Cambrian-Lower Ordovician. The black shale lies with strong unconformity above the gray shales and the carbonates, the latter being Upper Cambrian to Canadian. The Berkshire schist is considered here as the metamorphic equivalent of the black Trenton shale.

In Late Cambrian to Early Ordovician it is believed that the carbonates were deposited in the vicinity of small islands, with algal reefs, while the gray shales were accumulating in the moderately deeper water to the westward. There seems to be no difficulty in assuming such facies change, and analogies are presented.

There is some evidence that the major part of the faulting took place in pre-Trenton time, with some further movement after the deposition of the black shale.

MINERAL ASSOCIATIONS AND TYPES OF URANIUM ORES ON THE COLORADO PLATEAUS

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Uranium ores from the Colorado Plateaus are classified in two main types: (1) uranium with vanadium, (2) uranium with copper and other metals. Each type is subdivided into highly oxidized or relatively unoxidized ore.

The vanadium-uranium ratio of the vanadiferous ores ranges from about 30:1 at Placerville and Rifle, Colo., to about 1:1 at Temple Mountain, San Rafael district, Utah. The chief uranium minerals of the highly oxidized ore are the uranyl vanadates: carnotite, tyuyamunite, and metatyuyamunite. The other vanadium minerals include roscoelite, vanadium hydromica, corvusite, fernandinite,

and hewettite, with small amounts of pascoite, hummerite, rossite, metarossite, steigerite, fervanite, hydrated vanadium pentoxide, and the sodium analogue of hewettite, the last two being new minerals whose descriptions will be published soon.

The unoxidized vanadiferous ores are black and contain a new black uranium mineral found in nine mines, pitchblende, and montroseite and at least two other low-valence vanadium oxides. They are associated with pyrite and small amounts of sulfides (or selenides) of lead, copper, zinc, cobalt, nickel, molybdenum, and silver. Melanovanadite, corvusite, and fernandinite may represent a transition to oxidized ore.

The oxidized nonvanadiferous ore is characterized by bright-colored secondary minerals: about 18 yellow, orange, or green uranium minerals, including hydrated oxides, carbonates, sulfates, phosphates, arsenates, and silicates, as well as many secondary blue or green copper minerals, 5 pink cobalt "blooms," and traces of molybdenum, lead, zinc, nickel, and silver.

The unoxidized nonvanadiferous ore is also black and contains pitchblende, the new uranium mineral mentioned above, chalcopyrite, pyrite, bornite, chalcocite, sphalerite, galena, and traces of cobalt, nickel, molybdenum, and silver.

EQUILIBRIA RELATIONS DURING THERMAL METAMORPHISM OF CARBONATE ROCKS

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By the use of thermochemical data and by approximating certain unknown heat capacity and entropy values, the equilibrium relations ($\Delta F = 0$), under ideal conditions and ignoring rock pressures, have been calculated for 14 reactions occurring during progressive thermal metamorphism of siliceous carbonates. The reactions considered involve calcite, dolomite, magnesite, α and β quartz, forsterite, enstatite, diopside, wollastonite, periclase, monticellite, α and β larnite, lime, and carbon dioxide.

The calculated equilibrium temperatures at one atmosphere CO_2 pressure range from 92°C for the reaction $MgCO_3 + SiO_2 \rightleftharpoons MgSiO_3 + CO_2$ to 877°C for the reaction $CaCO_3 \rightleftharpoons CaO + CO_2$. These equilibrium temperatures are in fairly good agreement with experimentally determined reaction temperatures. However, the consistent deviation of the experimentally determined reaction points in the lower temperature reactions from the theoretical values shows that the speed at which equilibrium is attained is already strongly retarded at a considerable distance from equilibria. Owing to the large time factor involved in metamorphism, the naturally occurring reactions are believed to take place much closer to the theoretical than to the experimental values.

The effect of rock pressure on the equilibria temperatures at one atmosphere CO_2 pressure is calculated using the Clapeyron equation by assuming that the CO_2 is squeezed out of the system. In this case rock pressures of 4000 atmospheres will cause a lowering of the equilibrium temperatures between 40° and 80°C depending on the change in the mole volume of the solids during the reaction.

STRATIGRAPHY AND STRATIGRAPHIC PALEONTOLOGY OF UPPER MIDDLE ORDOVICIAN ROCKS, FILLMORE COUNTY, MINNESOTA

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The rocks between the Glenwood and Maquoketa formations are susceptible to sound classification on lithologic grounds alone. Faunal distribution parallels rock boundaries, and zones are of value principally for regional correlations.

The Platteville formation is a dominantly carbonate sequence between the Glenwood and the shales of the Decorah formation; it consists upward of the Pecatonica sandy dolomitic limestone member, with multiple corrosion zones at its top; the McGregor limestone member with a corrosion

zone near its base; and a newly recognized member of interbedded limestones and thin shales, with a prominent bentonite at or near its base in Fillmore County. The Decorah shale contains the Spechts Ferry bentonite near its base, locally displays hematite oölites, and is not divisible into the members recognized to the southeast. The Galena formation consists of three members: a newly recognized basal unit of cyclical limestones and shaly limestones; the Prosser limestone, with a group of corrosion zones at its top; and the Stewartville dolomitic limestone, with a feldspathized shale near its base. The Dubuque formation of interbedded limestones and shales contains a feldspathized shale which, like the one in the Stewartville, is believed to be an altered bentonite. The Dubuque is thought to be highest Middle Ordovician; its fauna is phylogenetically successive to that of the Prosser.

Comparisons of macrofossil faunules with those reported from type Black River and Trenton show disparities so great as to make the terms Black River and Trenton meaningless in southeastern Minnesota.

JERSEY DODGER LEAD-ZINC ORE BODIES, SALMO, B.C.

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The Jersey lead-zinc ore deposit is a low-temperature lead-zinc replacement in dolomitic limestone. The localization of the ore is controlled by folding, and locally by brecciation and small scale faulting.

The relationship of the underlying skarn bands and granite to the ore body is discussed. A possible origin for the lead and zinc in the ore is suggested.

COPPER SHALES OF GERMANY AND MICHIGAN

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The copper deposits at the base of the Nonesuch shale of northern Michigan and those of the Kupferschiefer of Mansfeld, Germany, have major points of similarity. Both contain copper sulfides finely dispersed in black organic shale that overlies a thick red terrestrial sandstone or conglomerate, gray at the top. Within a zone 1 to 2 feet above this sandstone, the shale contains about 3 per cent copper. Areally, individual ore concentrations are measurable in square miles, and copper occurs sporadically for scores of miles. Copper is concentrated in shallow depressions in the top of the sandstone, probably within a few miles of the ancient shore line. Highly fractured areas may or may not be rich; some rich areas have few, if any, fractures.

Major differences are that the Kupferschiefer contains bornite and subordinate amounts of chalcocite and chalcopyrite; the sulfur-poor Nonesuch contains chalcocite, minor amounts of native copper, and traces of bornite or chalcopyrite. At White Pine, Michigan, the sequence of sandstone and copper shale is repeated cyclically, with a copper-bearing siltstone above each copper-shale bed; copper per unit area is over five times that at Mansfeld. Marine limestone overlies the Kupferschiefer; gray siltstone overlies the Nonesuch deposits. Noteworthy amounts of lead and zinc are found only in Kupferschiefer.

Copper in the Nonesuch shale is believed to be an original sedimentary constituent, a view held by many students of the Kupferschiefer. In both formations the copper is closely related to sedimentary facies and only locally affected by structural features.

GEOLOGY AND ORE CONTROLS AT THE GUADALUPE MINE, NUEVO LEON, MEXICO

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Control of the sphalerite-silver-galena-barite deposits of the Guadalupe Mine, Nuevo Leon, Mexico, is exercised by structural intersections, by the differing responses to stress of the different

host rocks, and by the local characteristics of deposition. The tonnage available is determined by the size of the remnants of the ore-bearing structures left by erosion.

A complex of stocks and dikes of porphyritic Laramide (?) igneous rocks, mostly dioritic, intruded a dome of Upper and Lower Cretaceous sediments, predominantly gray limestone and black limy shale. Faults, some flat and some moderately dipping, cut both sediments and igneous rocks. Where these faults occur completely within shale, they are merely thin sheared zones and contain only traces of the ore minerals. Faults in limestone are generally tight shears enclosing thin lenses of barite. The best ore shoots occur along the lines of intersection of flat faults with vertical dikes in shale, where pencil-shaped breccia zones were formed in which the ore minerals were deposited.

As the mineralization proceeded almost exclusively by open-space filling, the size and openness of each breccia zone determined the size and grade of that ore shoot. As most of the productive faults have closed outcrop lines around the hills, the greatest possible length of each ore shoot, and consequently an upper limit to its potential tonnage, can be found by projecting the intersection of the controlling fault and dike from the presently exposed face to the outcrop.

CAMBRIAN CONTACTS IN EASTERN PENNSYLVANIA

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The Cambrian sequence in eastern Pennsylvania is:

Upper	Allentown limestone
	Limeport limestone
Middle (?)	Leithsville limestone
Lower	Hardyston quartzite

All ages, save for the barren Leithsville, are paleontologically established. The Hardyston overlies Precambrian gneisses; the Allentown is surmounted by the Ordovician Beekmantown limestone. Only the Cambrian-Precambrian and Allentown-Limeport contacts are defined in the literature. Because of lack of understanding of the Leithsville-Limeport relations, the age of the barren Leithsville has been questioned. Study of new and restudy of old exposures indicate that Hardyston-Leithsville relations fluctuate between transition and disconformity, the Leithsville-Limeport limestones are mutually transitional thereby implying a Middle Cambrian assignment to the Leithsville, and the Beekmantown is ordinarily in disconformable contact with the Allentown. In at least one instance supposed Beekmantown overlies the Limeport in disconformity.

EARLY PRECAMBRIAN ROCKS OF WESTERN QUEBEC

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During recent years considerable territory in western Quebec and the adjacent parts of northeastern Ontario underlain by Archean rocks has been remapped on scales ranging from 500 to 1500 feet to 1 inch. This paper is partly a short description of the lithological character, structure, and relationships of the surficial bedrock formations of this region, and partly a consideration of the problems of nomenclature, correlation, and origin that the information afforded by this new work presents.

The Early Precambrian surficial rocks of the area occur in three east-west trending belts: to the north, a highly folded, widespread, conformable, volcanic succession, usually called Keewatin but named Abitibi series by the writer; to the south, the siliceous mica schist with some interbedded volcanics of the Pontiac group occurring in a zone about 10 miles wide, and over 100 miles long; and between the Abitibi series and the Pontiac group, a synclinorium of Timiskaming conglomerate and graywackes more than 125 miles long.

Some of the most interesting features of these Early Precambrian formations are:

(1) the great structural unconformity that separates the Timiskaming sediments from the rocks of the Abitibi series and the Pontiac group

(2) the enormous thickness of coarse, poorly sorted, heterogeneous conglomerate at the base of the south limb of the Timiskaming synclinorium in the Rouyn-Beauchastel area of western Quebec

(3) the occurrence of thin beds of laminated graywacke interstratified with the conglomerate even where it contains boulders up to 5 feet in diameter.

(4) The intrusive granitic rocks of the belt of banded gneisses that separates the rocks of the Grenville subprovince from those of the Timiskaming subprovince intrude the sediments of the Grenville series, the Pontiac group, and the Timiskaming series but are overlain unconformably by the Huronian Cobalt series.

REVISION OF MIDDLE (MOHAWKIAN) AND UPPER (CINCINNATIAN) ORDOVICIAN STRATIGRAPHY*

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Mohawkian sediments in New York, Ontario, and the Ottawa-St. Lawrence Lowlands have been interpreted for about 100 years as a sequence of successively younger formations, and all have been thoroughly named as such. A reconstruction of paleoecological conditions, based on a recent study in south-central Ontario, indicates that the Black River and Trenton groups were deposited contemporaneously. Each "formation" is a phase of deposition, of which the lithology and the fauna reflect the environment. The Black River sediments are the near-shore equivalents of the Trenton sediments. The Mohawkian was deposited in a transgressive sea, whereas the repetition of Mohawkian phases in the Cincinnatian in reverse order indicates a regressive sea. Similar environmental conditions during the transgressive and regressive stages of the Middle-Upper Ordovician sea explain why the Cincinnatian fauna is a "recurrent" Mohawkian fauna.

BLISTER HYPOTHESIS AND GEOMORPHOLOGY

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Arid and submarine regions best exemplify diastrophic and volcanic effects with the least gradational modification. The most typical topographic forms in such areas are basins and domes. A correlation between the sial-sima composition of the rocks with the breadth of these forms is suspected. They are less broad in predominantly sialic Africa than on the floor of the Pacific and much of the floor of the Atlantic. If these swells represent blisters in different stages of development such variation in dimensions is expectable. Doming is usually steady as blisters grow, and the resultant land forms depend upon the ratio of expansion to gradational velocities. Periodically, a change of physical state in part or all of the blister material results in a sharp velocity increase of diastrophism, producing uplifted erosion levels and rejuvenation. Movement in the marginal mountain regions is also partially continuous and partially spasmodic. Inverse or negative movements result from blister collapse and accompanying phenomena. These result in drowning and premature aging of land forms. The ever-changing position of sea level represents one of the most critical controls in surface evolution. The development of blisters beneath the sea and on land adjacent to the sea explains such changes.

The presumed decrease of radioactivity in depth suggests stable vertical gravitational and thermal equilibrium below the surface. This precludes convection currents but permits the development of blisters. Submarine and terrestrial evolution is best explained in terms of blister evolution.

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CHANNEL EQUILIBRIA, BRANDYWINE CREEK, PENNSYLVANIA

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Measurements of the channel of Brandywine Creek in southeastern Pennsylvania indicate an orderly progressive change in channel shape from the uppermost headwater tributaries to the mouth of the trunk stream. With increasing discharge in the downstream direction at a constant duration of flow, the width increases as the 0.56 power of discharge while depth increases with discharge to the 0.4 power. These progressive downstream changes in width and mean depth prevail at low as well as at high flow. These exponents are similar to those found in numerous river basins of much larger drainage area.

The rates of change of width and depth on the Brandywine are remarkably similar to those observed in regime or stable canals in India, Egypt, and the United States. The term regime is applied to irrigation canals which have developed over a period of time a stable channel shape and profile presumably representing an equilibrium between the water and sediment carried by the stream. The close analogy between the behavior of the Brandywine and that of the equilibrium canals suggests that the channel of the Brandywine also represents an equilibrium adjustment. This channel equilibrium extends to the headwater reaches having contributing drainage areas as small as 0.1 square mile.

In the region of diverse lithology through which the Brandywine passes, the longitudinal profile of the creek possesses numerous knickpoints. Thus, channel equilibria may exist even on a stream with a nonuniform concave longitudinal profile.

ORIGIN OF TEXTURAL FEATURES OF CERTAIN CHERTS IN THE TRI-STATE DISTRICT

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A mottled texture and variations in color and luster are characteristic of the chert in the "sheet-ground" horizon at the property operated by the National Lead Company west of Baxter Springs, Kansas, in the Tri-State District.

Exposures underground exhibiting transitions from limestone to chert show the mottled texture to be a criterion of the epigenetic origin of the chert.

In addition, these exposures relate certain combinations of color and luster to well-defined stages in the gradual chertification of the original limestone. The stages thus established serve as a measure of the local intensity of chertification.

GRAVITY OBSERVATIONS AT SEA. PART I: THE BAHAMAS ISLANDS REGION

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Simple Bouguer and free-air anomalies for 234 new gravity observations in the deep water of the Bahamas Islands region are reported. Bouguer gravity anomalies for 326 points in the shallow-water areas of the Bahamas Islands have been provided by oil companies and oil-prospecting companies. Anomaly maps are presented combining all available data. Predominantly the anomalies can be explained by simple erosion of the deep-water portions without compensation, or alternately construction of the shallow-water portions with regional compensation. This is superimposed on a small seaward increase of gravity. A negative free-air anomaly of about 110 milligals follows the eastern boundary of the Bahamas and the southern part of the Blake Plateau. The greatest part of this anomaly

can be explained by the above process, possibly complicated by boundary effects of the isostatic compensation.

GLACIAL HISTORY OF THE MENTASTA MOUNTAINS, SOUTHEASTERN ALASKA RANGE

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The Mentasta Mountains constitute a relatively low segment of the Alaska Range. Therefore their glacial history apparently differs from that of the higher central and western segments of the Alaska Range. Instead of a series of local glaciations of varying intensity, the principal event was an invasion of ice from the Wrangell Mountains, 60 miles to the south across an arm of the Copper River basin.

Early local glaciations in the Mentasta Mountains produced cirques and U-shaped valleys. The area was then invaded by foreign ice, which penetrated to the headwalls of some of the previous cirques, suggesting that this ice overwhelmed such local ice as may have formed during the onset of this glaciation. Erratics of vesicular volcanic rocks in the drift, and the general northeastward slope of the lateral drainage channels formed on flanks of large valleys during wastage of the foreign ice indicate that the source of foreign ice was the Wrangell Mountains to the south.

After wastage of the Wrangell ice, the cirques were reoccupied by glaciers or rock glaciers. Some glaciers extended as much as 10 to 15 miles down valleys that had previously been filled with Wrangell ice to a thickness of more than 1000 feet. These local glaciers have since retreated to the valley heads, and most of them have disappeared.

LITHOLOGIC ORE CONTROLS IN SANDSTONE TYPE URANIUM DEPOSITS, COLORADO PLATEAU

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The importance of lithology in localizing uranium deposits in the Morrison formation has long been recognized. Most ore bodies have been found in sandstones more than 40 feet thick where the Salt Wash member of the Morrison has about equal proportions of sandstone and mudstone.

The discovery and development of ores in other parts of the geologic column has re-emphasized the significance of lithologic control. Although deposits are known in sedimentary formations ranging in age from Permian to middle Tertiary and are widely scattered in large parts of several States, it has been found that most ores are included in (1) fluvial sandstones which (2) contain carbonized plant matter, (3) are not red, and (4) are usually arkosic.

Host-rock control is particularly striking in the Permian where certain favorable but very limited arkose beds are mineralized in a thick section of barren, unfavorable eolian sandstones and red beds.

Most deposits show no apparent structural control.

The marked lithologic control suggests introduction of uranium in solution at the time of deposition of the enclosing sediments. Uranium was derived from the provenance of the sediments and was precipitated in certain favorable sedimentary environments, under reducing conditions, and in the presence of carbon. The original distribution was later modified by ground water.

Sandstone uranium deposits may be the continental analogue of uranium-rich marine black shales and phosphorites. Uranium moving seaward in streams during erosion of a land mass may be fixed on the continent by certain favorable fluvial sediments to form sandstone-type ore deposits; or the uranium may be carried on to the sea, for possible later fixation by certain favorable marine sediments.

Uranium-lead age determinations on sandstone ores represent an apparent contradiction to the theory.

ZIRCONS AS PROVINANCE INDICATORS

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A recent study of a Scottish granite intruded into Moine "granulites" showed that, while the greater part of the granite was clearly magmatic, there was considerable granitization near the contact in some areas. The magmatic origin of the granite was shown by field evidence, and by microscopic, chemical, and trace-element studies; the granitized Moine could be differentiated from the normal granite without difficulty. The accessory zircons in these rocks were studied, and it was found that zircons from the granite are idiomorphic, while those from the Moines are well rounded. Furthermore, zircons from contaminated granite are similar to those from the normal granite, but they are very elongated; and zircons from the granitized Moines are recrystallized and idiomorphic, but quite distinct from those in the granite. It is suggested that this technique may have wider uses in similar studies.

SYNTHESES AND STABILITY OF THE MUSCOVITES

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The syntheses of randomly stacked one-layer monoclinic muscovite (1Md = illite), one-layer monoclinic muscovite (1M), and two-layer monoclinic muscovite (2M) have been accomplished. The upper stability limits of muscovite are represented by a curve passing through the points 625° C.—5000 psi water vapor pressure, 665°—15,000 psi, and 715°—30,000 psi. Above this curve sanidine + corundum + vapor are the stable phases.

The stability ranges of the muscovite polymorphs named could not be fixed accurately because of the sluggish nature of the transformations. However, the following transformations were effected: 1Md → 1M → 2M. It is believed this sequence obtains in the progressive metamorphism of sediments. The first transformation is probably dependent on factors affecting reaction rate. The second trans-trigonal may be related to a univariant curve of equilibrium (*i.e.*, an isograd). The three-layer trigonal muscovite (3T) was obtained in only one run with 2M muscovite, and its synthesis is therefore not substantiated.

Experiments on reactions alleged to represent a biotite isograd indicate that the muscovite-chlorite-quartz schists undergo the following reaction: muscovite + 2 clinochlore + 4 quartz ⇌ phlogopite + 2 cordierite + 8 water. The growth of biotite according to this reaction in low-grade metamorphic rocks must be accompanied by another phase (*i.e.*, cordierite). Growth of biotite as a result of other reactions will not be of equivalent grade. The upper stability curve of muscovite marks the conditions of the second sillimanite (or orthoclase) isograd.

A comparison of the upper stability curve of muscovite with the minimum melting curve of the "granite" system suggests that muscovite may form in granitic magmas above approximately 25,000 psi water vapor pressure and in the solid state below that pressure in granitic rocks. These relations may account for the apparent two generations of muscovite in some granites.

Data have also been obtained on the muscovite-leucophyllite, muscovite-paragonite, and muscovite-quartz joins.

THERMOLUMINESCENCE OF ARTIFICIALLY PRECIPITATED CALCITE

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A number of experiments have been performed in which calcite has been precipitated from solutions containing varying concentrations of impurity ions. Some of the impurities such as manganese

and strontium appear to serve as activators for thermoluminescence. Iron generally inhibits the thermoluminescence of calcite. In some instances, specific electron trapping centers appear to be assignable to specific impurities.

A second series of experiments has been carried out in which limestones containing their natural impurities have been dissolved in acid and reprecipitated under conditions of increasing pH. These experiments indicate that certain impurities are included in the crystal lattice of calcite precipitated under specific pH conditions, since the thermoluminescence glow-curves change markedly with changing pH. It is hoped that detailed examination of these changes will yield information about the pH of the solutions from which natural calcites have been precipitated.

In order to attempt to simulate geological conditions to a slight degree, some of the precipitates have been subjected to high pressures, and attempts have been made to recrystallize some of the samples. Pressure effects are complex, but there appears to be a general reduction in low-temperature thermoluminescence of precipitates which have been subjected to high pressure.

Editor's Note: *The following abstract was received too late to be included in proper alphabetical sequence*

STRUCTURAL GEOLOGY OF SOUTHEASTERN COAHUILA AND ADJACENT PARTS OF NUEVO LEON, MEXICO*

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The area discussed lies south of the cities of Saltillo, Coahuila, and Monterrey, Nuevo Leon, comprising approximately four 30-minute quadrangles which are crossed in northwest-southeast direction by the arcuate folded ranges of the Sierra Madre Oriental.

The rocks are predominantly marine sediments ranging in age from Upper Jurassic (Argovian) to Upper Cretaceous (Santonian), consisting of limestones, shales, gypsum, and phosphorite. Intrusive rocks are stocks of granodioritic composition, and the extrusives are chiefly andesite flows.

The field study enabled the recognition of three structurally distinct belts of the Sierra Madre Oriental which are, from northeast to southwest, the Valley and Ridge Belt, the Basin and Range Belt, and the Mineral Belt. The sedimentary section thins from 14.000 feet in the Valley and Ridge Belt to 6000 feet in the Mineral Belt. Folding in all three belts is highly developed on a gypsum or siltstone base producing *décollement*. Normal faulting is characteristic of the Basin and Range and of the Mineral belts; in the latter it is preceded by high-angle thrusting. Igneous rocks are confined to the Mineral Belt.

The three-fold structural development is correlated with the thickness gradation of the sediments. Thick accumulations lent themselves to plastic deformation whereas thinner ones were fractured. Causal relationship is seen between highly developed fracturing and igneous activity which in turn resulted in commercial mineralizations. The tracing of these belts to other parts of the Sierra Madre Oriental System, or the recognition of these, may lead to a better understanding of the tectonics of eastern Mexico and the distribution of its mining districts.

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ABSTRACTS OF PAPERS SUBMITTED TO MEETING AT STANFORD UNIVERSITY, CALIFORNIA, MARCH 27–28, 1953

CORDILLERAN SECTION (GSA)

CLASTIC DIKES IN QUATERNARY LAKE SEDIMENTS IN OREGON

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Numerous clastic dikes are exposed in deflation basins excavated in Quaternary lake sediments in Fort Rock Valley, northern Lake County, Oregon. They range up to several hundred feet long and from a fraction of an inch to many feet in width. Although the wall rocks are mostly fine-grained volcanic ash and diatomite, the dikes are mainly cemented sand, sandy pumice, and coarse grit. Differential erosion by wind and rainwash has left them standing in relief. They conform in structure to the joint and fault patterns of the area, but with one exception the adjoining lake beds generally show little or no obvious displacement. Evidently the dikes were injected from below, presumably with the aid of water and because of minor movements of the fault blocks that underlie the dry lake basin.

LATE CENOZOIC STRUCTURE AND SEDIMENTATION OF THE SANTA FE AREA, NEW MEXICO*

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The Santa Fe area—a 15-minute quadrangle, with Santa Fe, New Mexico, in the northeast part—is on the east border of the Rio Grande trough. Precambrian and some Pennsylvanian rocks form the mountains along the east border, and Permian through Mesozoic rocks are exposed just south of the Santa Fe area. In the southwest part are late Eocene sandstone and mudstone, and Oligocene-Miocene latite breccia and intrusive monzonite. West-dipping, upper Miocene-lower Pliocene sandstone of the Santa Fe (restricted) formation forms the northern third of the area. Most of the area is covered by an early Pleistocene (?) sand and gravel unit, up to 300 feet thick. Early Pleistocene (?) basalt caps the west part of the area.

Late Miocene (?) faults trending north-northwest and east-northeast are inferred from geologic, topographic, geophysical, and hydrologic data. In middle or late Pliocene (?) time the mountains were further raised, and the Santa Fe was faulted and tilted west 10°–15°. Erosion removed the Santa Fe from the southern part of the area and produced a west-sloping, graded surface. Deposition of the early Pleistocene (?) sand and gravel unit was interrupted by erosion, which beveled the angular unconformity; this second graded surface is preserved by basalt tuff and flows. The flows diverted the westward drainage and formed a temporary base level for the Santa Fe area. The second surface was modified, and, when Santa Fe Creek cut through the flows, present dissection began.

UP-SIDE-DOWN GRADED BEDDING IN RIGHT-SIDE-UP LACUSTRINE PUMICE

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In the north end of Owens Valley, California, a widespread pumice layer of Pleistocene age, composed of angular fragments, exhibits graded bedding of the sort usually considered to indicate up-side-down beds—that is, from fine at the bottom to coarse at the top. The regional relations prove that the layer is not up-side-down. Pumice has the unique characteristic among common rock fragments of floating in water until partly saturated, and the reverse graduation is a normal result of

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airborne pumice falling into standing water. The smaller particles become saturated more quickly than the larger fragments and therefore sink first.

Other kinds of pumiceous deposits in the area do not exhibit reversed order in graded beds. The unconsolidated basal member of the Bishop tuff of Gilbert (1938) consists of rhyolite ash in which well-rounded pumice fragments are distributed at random. Gilbert concluded that his Bishop tuff originated from eruptions of the nuée ardente type. Pumice deposited by running water is usually admixed with other sedimentary material, the pumice fragments are rounded, and graded beds display the common order from coarse at the bottom to fine at the top. Although no airborne pumice that fell on dry land was recognized, the logical expectation is that any size gradation of the fragments would be from coarse at the bottom to fine at the top.

ARVIN-TEHACHAPI AND BAKERSFIELD EARTHQUAKES OF JULY–AUGUST 1952

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The Arvin-Tehachapi July 21 earthquake, magnitude 7.5, was the strongest in southern California since 1857. It was felt from San Diego to San Francisco and Reno. At least 16 deaths resulted. Damage totalled tens of millions of dollars. Half of the causal northeast-trending White Wolf fault lies beneath San Joaquin Valley alluvium; northeast half traverses Tehachapi Mountains intrusive rocks.

Besides usual earthquake consequences—damage to weak structures, fissuring of alluvium, landslides, huge changes in spring and stream flow—these earthquakes presented several unusual features. The White Wolf fault trends normal to the San Andreas system, is probably of reverse dip-slip habit, is short for the earthquake magnitude, gave little previous indication of being active. Instead of a simple single trace the fault in bedrock is marked by a complex pattern of ruptures a mile wide. Main-shock epicenter was at Wheeler Ridge, the fracture developed entirely northeastward for about 40 miles. Shock intensity was apparently rather low for the magnitude, and unsymmetrical—higher to the southeast of the fault. The main earthquake was followed by strong shocks on faults presumably normal to the White Wolf (among them July 29, magnitude 6.5, origin about 10 miles east of Bakersfield; August 22, magnitude 6.0, about 3 miles southeast of Bakersfield and causing severe destruction there).

One tectonic explanation of White Wolf fault slip is release of northwest-southeast compressive strain engendered by obstruction to San Andreas displacement by curvature at Tejon Pass and more westerly trend of San Andreas to the southeast.

SILICA-VARIATION DIAGRAM, NORTHEASTERN UMNAK ISLAND, ALASKA

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Quaternary lavas on northeastern Umnak, in the eastern Aleutian arc, range from olivine basalt with 46 per cent of silica to rhyolite with 73 per cent of silica. The silica-variation diagram is based on analyses of six analyzed porphyritic lavas. The least siliceous nonporphyritic basalt contains 52.5 per cent of silica.

In the range from 48 to 52.5 per cent of silica, curves are established by groundmasses of four porphyritic basalts. In this low-silica end of the diagram, the magnesia curve falls from 11 to 4 per cent; lime falls from 13 to 9 per cent; iron rises from 8 to its maximum of 12 per cent; soda rises from 2.5 to 3.5 per cent; and potash from 0.8 to 1.2 per cent. Alumina ranges from 15 to 18 per cent irrespective of silica.

In the range from 52.5 to 73 per cent of silica, the magnesia curve falls nearly to zero; lime to 1.5 per cent; iron to 3 per cent; alumina to 13 per cent; whereas both the alkalis rise to slightly more than 4 per cent.

The northeastern Umnak curves are similar in the basalt range to those derived by H. Kuno for basalts of Hakone Volcano, Japan, and by C. A. Anderson for basalts of the Medicine Lake Highland, California. The curves indicate a liquid line of descent caused by fractional crystallization; some resolution of crystals (now phenocrysts) by liquid is inferred to account for the steep rise in lime and magnesia with the decrease in silica.

AGE OF THE OBSIDIAN FLOW AT GLASS MOUNTAIN, SISKIYOU COUNTY, CALIFORNIA

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Samples of wood from standing buried tree trunks in a bed of pumice at Glass Mountain, eastern Siskiyou County, California, were subjected to tests employing the radiocarbon method and assigned a maximum age of 1660 ± 300 years, a minimum age of 1107 ± 380 years, or an average age of 1360 ± 240 years. The trees were killed by the pumice fall, and this places the age of the pumice at no more than 1660 ± 300 years or no less than 1107 ± 380 years. On this basis, the age of the rhyolite obsidian flow that overlies the pumice cannot exceed 1660 ± 300 years.

STRUCTURAL TRANSITION ZONE BETWEEN COLORADO PLATEAU AND BASIN AND RANGE PROVINCES IN SOUTHWESTERN UTAH

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In the southwestern corner of Utah the transition from Colorado Plateau structure on the east to Basin and Range structure on the west takes place within a complex fault block, extending about 25 miles west from the Hurricane fault and over 60 miles north from the Arizona border.

North-south Tertiary faults intersect northeasterly trending Laramide structures in this transition zone; both structural trends controlled Quaternary movements. Major structural features include two asymmetrical Laramide anticlines, five Tertiary laccolithic intrusions from 10 to 60 square miles in exposed area, and many steep faults active during the Quaternary.

Moderate orogenic warping in the Late Jurassic or Early Cretaceous was followed by deposition of 4000 to 5000 feet of Upper Cretaceous shallow-water geosynclinal sediments. Folding, minor thrusting, and erosion near the end of the Cretaceous preceded deposition of the Eocene Claron formation. The numerous orogenic pulsations recorded in central Utah apparently did not affect this southwestern area; absence of evidence of movement within the Upper Cretaceous and within the Claron delimits the main Laramide movement.

Claron deposition was closely followed by the formation of welded tuffs, then bedded pyroclastics, breccias, and flow rocks. This Tertiary volcanic sequence contains two unconformities, representing either orogenic disturbances or intrusive folding. Tertiary volcanism culminated in the intrusion of laccolithic masses at three stratigraphic horizons in the sediments underlying the volcanic rocks. Intermittent block faulting and extrusion of thin basalt flows accompanied general uplift of the area during the Quaternary.

TRANSVERSE-RIDGE PATTERN ON THE COASTAL SAND DUNES OF OREGON

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Characterization of dune patterns is a more useful procedure than an attempt to define various types of dunes. The transverse-ridge pattern is richly developed on the coastal dune sheets of Oregon wherever the shore is bordered by a level strip free from obstacles. The ridges lie essentially at right angles to the north-northwest sea breeze of summer. Each ridge has the familiar gentle windward slope and slip-face to leeward.

Slow-motion photography of smoke streams demonstrates that, contrary to assertions found in many research publications and text books, there is no powerful fixed eddy in lee of the summit that sweeps sand backward and steepens the lee slope. The turbulent boundary layer of the main air stream leaves the sharp edge at the top of the slip-face as a vortex layer. Beneath it is a body of stagnant air through which drops the sand carried outward in the vortex layer, most of it falling on the slip-face.

In winter the southwest gales partially destroy the transverse-ridge pattern but, because of the wetness of the sand, cannot establish a corresponding system of their own.

The transverse-ridge pattern is commonly assumed to be confined to deserts and semiarid regions. The present study shows that it occurs also on coastal dunes where precipitation is very high, provided there is a long enough dry season with wind regular in occurrence and constant in direction.

TIME RANGES OF SOUTHERN CALIFORNIA TERTIARY FORMATIONS

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A regional correlation chart is presented showing time ranges of most-used formation names according to a concensus of authorities. Overlapping correlations of most formations with those above and below show them to be diagonal in time and space. Their contacts are at different time levels at different places, and thus in most instances do not coincide closely with any time divisions. Misuse of many formation names regionally through lack of proper local names is brought out.

Formations are correlated both by megafaunal and microfaunal stages as co-ordinated by a concensus of authorities. Time lengths of stages are compared. Well-defined megafaunal stages, long recognized and used, have been confused with formations, and many names are misused for formations regionally.

The time ranges of the formations are shown related to a curved line representing the generalized amount of regional sea transgression. Most major depositions of coarser clastics coincide with emergences, and major shaley deposits with submergences.

The regional curve profile, showing three gradual general transgressions with three abrupt regressions, is superimposed on a separate profile of several lesser emergences and submergences (not entirely regional) which appear related to faunal stages. Fluctuations due to local deformations were almost continuous. Most coarser formations are due to secondary or local uplifts near their basins.

PEBBLY MUDSTONES AND TILLITES

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Massive marine mudstones containing scattered pebbles crop out in California in the Knoxville formation (Jurassic) at Grindstone Creek, Glenn County; in the Chico group (Cretaceous) at Pigeon Point, San Mateo County; and in the Pico formation (Pliocene) at Santa Paula Creek, Ventura County. The unsorted and ungraded lithology, with widely dispersed pebbles, requires explanation.

The pebbly mudstones of the Knoxville crop out as lenticular beds as much as 100 feet thick that contain rare slump structures and are interbedded with graywacke, mudstone, and conglomerate, which were in part laid down by turbid flows as shown by graded bedding, flow casts, edgewise conglomerates, and current bedding. At Santa Paula Creek, where deep-water marine sediments were deposited by turbidity currents, and at Pigeon Point, successive stages in the origin of the pebbly mudstones are preserved. Beds of graded conglomerate, laid down on soft water-saturated mud, became unstable and slumped downslope, mixing the pebbles with the mud.

Pebbly mudstones originating by this process are similar to many rocks designated as tillites. In fact, times of glaciation have been introduced into geologic history, based on the interpretation of such rocks as tillites, without such independent supporting evidence as striated pavements. It is suggested that such "tillites" be restudied, for they may have originated by slumping and mixing of interbedded gravel and mud penecontemporaneously with deposition.

WHITE WOLF FAULT IN RELATION TO GEOLOGY OF THE SOUTHEASTERN MARGIN OF SAN JOAQUIN VALLEY, CALIFORNIA

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The southern Sierra Nevada and Tehachapi Mountains are made up of a pre-Cretaceous crystalline complex composed of Jurassic (?) plutonic rocks with hornblende-biotite-quartz diorite predominating, and linear inclusions of Paleozoic (?) schists, quartzite, and marble, the crystalline rocks

being overlain by a Tertiary-Quaternary marine and continental sedimentary series cropping out along the foothill areas and underlying the San Joaquin Valley where the series thickens southwesterly to an estimated total of about 28,000 feet just north of Wheeler Ridge. The Tertiary series dips under San Joaquin Valley with the crystalline-rock contact sloping southwest at an average angle of about 6°, steepening to about 20° immediately northwest of the White Wolf fault.

The White Wolf fault, nearly parallel to the Garlock fault and about 18 miles northwest of it, is a major fault traceable from Tehachapi Canyon southwest along the base of the steep northwest slope of Bear Mountain for 17 miles, and probably extends under San Joaquin Valley toward Wheeler Ridge. The southeastern block has been elevated on this fault to a maximum displacement of at least 10,000 feet as indicated by surface and subsurface data, with the maximum displacement near the mouth of Sycamore Canyon.

Surface effects along the White Wolf fault zone produced on July 21, including overthrusting in the "mole-track" scarplets formed, shortening of fences and the railroad tracks crossing the fault, and dips of the more-continuous fault-trace ruptures, strongly suggest thrusting. Seismographic evidence favors a high-angle reverse fault at depth. Ground cracks and small pressure ridges oblique to the fault trace, and small ground offsets evidence some left lateral movement.

The White Wolf fault is essentially a reverse fault, locally a thrust, elevated in the southeast block, with a small left lateral component of movement. It is more closely related to the Garlock and Pleito faults than to faults in the northern part of the area mapped.

VOLCANIC ERUPTION OF SAN BENEDICTO ISLAND, MEXICO

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On August 1, 1952, the uninhabited, deep-sea volcanic island of San Benedicto in the Revillagigedo Archipelago 300 miles off the west coast of Mexico burst into an explosive volcanic eruption for the first time in recorded history. San Benedicto is the easternmost of four islands of a linear Pacific Basin chain along which volcanism appears to have progressed from west to east. Within 2 weeks a steep-sided ash and cinder cone over 1000 feet high was built. Violent gas and smoke emanations from the half-mile-wide symmetrical crater of "Boqueron" (Big Mouth) continued until the middle of September and was witnessed by Dietz and others on two flights to the island. By September 20 a small core of lava plugged the magma conduit, and the volcano remained relatively dormant until early November when Richards observed that extrusions of blocky lava half filled the deep crater. Additional lava was extruded later in November. Commencing December 9 Richards and Lewis Walker spent 4 days at San Benedicto, arriving 2 days after blocky lava had breached the pyroclastic cone at its eastern base. This latest lava flow built 900 feet out into the sea in 24 hours. After the second day the "delta" of lava was advancing seaward at a rate of approximately 150 feet per day. The extensive collection of aerial photographs taken on previous flights to the island was supplemented by motion pictures of eruptions taken from inside the crater on December 10.

SOFAR DETECTION OF MYOJIN REEF ERUPTION OFF JAPAN

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On 17 September 1952 the MYOJIN MARU discovered a new, largely submarine, eruption 200 nautical miles south of Tokyo and adjacent to the periodically active Bayonnaise Rocks which are considered to lie along the Fuji volcanic zone. A series of great explosions accompanied the extrusion of augite-hypersthene dacite. Since 26 September, when the main series of explosions ended there has been only sporadic activity.

Because of its remoteness, only a few visual observations were made of Myojin. Additional data were obtained from a tsunami recorder on Hachijo Island, 130 kilometers north of Myojin, which detected several tsunamis initiated by the volcanic eruptions. A rather complete record of the Myojin activity was recorded by the U. S. Navy Sofar stations at Point Sur and Point Arena, California, about 8600 kilometers from the scene of the activity. Over 100 explosions were detected, one of which

lasted for more than an hour. A comparison of the explosions recorded on Sofar equipment shows good agreement in time with those observed visually or inferred from tsunami data.

From the tsunami data and the Sofar records it was independently concluded that the Japanese Hydrographic Vessel No. 5, the KAIYO MARU, was destroyed by a large eruption at about 1221 Tokyo time, 24 September. All 31 people aboard the vessel were lost.

This is believed to be the first time any Sofar signals have definitely been identified as of volcanic origin, and, since some of the signals were distinctive, it is suggested that Sofar may prove of value for monitoring oceanic volcanic activity.

GROUND-WATER TEST DRILLING PROGRAM OF THE U. S. BUREAU OF RECLAMATION, SAN JOAQUIN VALLEY, CALIFORNIA

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The Bureau of Reclamation commenced its coring program for the San Joaquin Valley in May 1950. Test drilling was considered necessary to supplement the insufficient and often inaccurate subsurface information available.

At present 64 test holes have been drilled, a total of 56,451 feet, 45 per cent of which was cored. Approximately 19,076 feet of core has been recovered, for an average recovery of 75 per cent. Coring has been in unconsolidated continental alluvium. Samples of core are taken for permeability, porosity, density, and specific-yield tests and for mineralogical studies.

Through inspection of the core record and the electric log, depths of the aquifers to be tested are selected. Five or six aquifers may be tested in each hole by setting a piezometer pipe with a sand point opposite the aquifer; packers are then placed in aquiludes above and below the sand point isolating the zone for testing. The piezometer pipes are a permanent installation for water measurements and sampling. To take a water sample from a piezometer pipe a jetting operation was devised.

X-RAY EXAMINATION OF DUMORTIERITE

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Dumortierite from three localities was studied with a view to resolving discrepancies among various descriptions of this mineral in addition to providing further data. A nearly complete set of measurements was obtained from a single crystal which was kept in a fixed position on a goniometer head; the latter was successively mounted on the two-circle goniometer, on the precession instrument, and on a special bracket fitted to the polarizing microscope permitting optical examination of the crystal in any desired refractive index medium. Thus error in correlation of morphological, x-ray, and optical data is minimized. All measurements were then verified using other crystals.

The composition $8Al_2O_3 \cdot B_2O_3 \cdot H_2O \cdot 6SiO_2$ suggested by Schaller in 1905 seems confirmed by the relation of measured density to densities calculated for various cell contents. Although orthorhombic, the lattice exhibits nearly perfect hexagonal pseudosymmetry which is emphasized by ubiquitous prismatic twinning at 60°.

Bowen and Wyckoff in 1926 demonstrated optically and by means of powder patterns that dumortierite begins to undergo decomposition at temperatures around 900°C., with concomitant crystallization of mullite ($3Al_2O_3 \cdot 2SiO_2$). A differential thermal curve to 1000°C. (at an average heating rate of 20° per minute) showed no significant deflections. A single crystal heated to 1300 ± 30°C. for about 7 hours was converted completely to mullite; the newly formed crystals show no preferred orientation.

MIOCENE AT CAPE BLANCO, OREGON

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Examination of the section of marine fossiliferous strata along the south side of Cape Blanco, Oregon, referred to the Empire formation (Pliocene) by Diller (1903), Bandy (1950), and others,

revealed an unconformity dividing the formation into two parts. The unconformity, marked by a moderately coarse conglomerate, is exposed in the sea cliff about half a mile southeast of the Cape and a short distance stratigraphically above the 25-foot tuff member noted by Diller. The *Securella [Chione] securis-Anadara trilineata* fauna is restricted to the beds above the conglomerate. The name Empire formation should be applied only to these upper beds.

In addition to the tuff member, the lower formation includes massive sparsely fossiliferous sandstones with occasional hard calcareous sandstone and conglomerate beds. The base of the lower formation was not determined; consequently its relation to the middle Eocene of Bandy (1950) is unknown, but judging from his map they occur in the same vicinity. *Mytilus middendorffii* Grewingk, *Mactra [Spisula]* sp., *Yoldia cooperi* Gabb subsp. *supramontereyensis* Arnold, *Bruclarkia oregonensis* (Conrad), *Nucella* sp., and *Kewia [Scutella] blancoensis* (Kew) were collected from the formation and indicate an age equivalent to the Astoria formation (Middle Miocene) of more northern areas. None of these fossils occur above the unconformity.

CHEMICAL CONSTITUTION OF SAPONITES, BOWLINGITES, SAUCONITES

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Serpentine minerals are characterized by significant variability not only of their optic properties but also of their chemical composition. The latter is expressed by varying values of the coefficient (K) characterizing the relationship $MgO:SiO_2$ in the chemical formula. In the chemical formulae of the serpentinites studied by us K may be higher than 1.5 (serpentines richer in MgO) as well as significantly lower than 1.5 (serpentines poorer in MgO), whereas in the accepted formula of serpentine—$H_4Mg_3Si_2O_9$ — K = 1.5.

Recently H. H. Hess has shown that for antigorite from Caracas K = 1.40.

Consequently it is possible to state a series of formulae for serpentine minerals with differing K values. These formulae permit us to explain the chemical constitution of saponites, bowlingites, hullites, chlorophäites, and many other similar minerals studied by the author in the Caucasus and the Ukraine. All these complex minerals may be considered products of an isomorphic isovalent replacement

$$Mg_3^{\cdot\cdot} \rightarrow Al_2^{\cdots} \text{ or } Mg_3^{\cdot\cdot} \rightarrow (Al, Fe^{\cdots})_2 \text{ or } Mg^{\cdot\cdot} + H^{\cdot} \rightarrow Al^{\cdots}$$

in the molecules of serpentine minerals with different K value. This point of view has been corroborated also by the data of x-ray investigations as well as by the data of thermal analyses.

Calculation of the molecular quantities in the analyses of saponites, bowlingites, hullites, and chlorophäites permits us to show that these minerals as well as the Zn-saponite-sauconite studied by Ross correspond quite exactly to the formulae of serpentine minerals. This suggests the existence of Zn-serpentines.

ASSOCIATION OF URANIUM AND OTHER METALS WITH CRUDE OILS, ASPHALTS, AND PETROLIFEROUS ROCKS

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The widespread association of uranium with organic material in sedimentary rocks has been recognized by many geologists studying uranium deposits but until recently has received little detailed study. During the past year the U. S. Geological Survey has been investigating the association of uranium and other metals with crude oils, natural asphalts, and petroliferous rocks.

Uranium analyses and semiquantitative spectrographic analyses of about 100 samples of crude oils, natural asphalts, and oils extracted from petroliferous rocks and of the ash of these materials indicate that uranium and other metals, including vanadium, nickel, copper, cobalt, molybdenum, lead, chromium, manganese, and arsenic, are consistently present, sometimes in unusually high concentrations. The uranium content of the analyzed samples ranges from less than 0.001 ppm to more than 62,500 ppm in the oils and asphalts and from less than 10 ppm to more than 100,000 ppm in the ash.

Although the chemistry of the metal compounds in petroleum is not definitely known, these metals probably occur in metallo-organic compounds and are concentrated in the heavy asphaltic part of petroleum. The high concentration of unusual elements in the ash suggests that these elements have a genetic relationship with petroleum and the petroleum source bed. The results of this investigation also suggest that in some uranium deposits petroleum may be the source material for the uranium and other metals.

ENGINEERING GEOLOGY OF THE RED BLUFF DAM SITE, CALIFORNIA

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The United States Bureau of Reclamation has studied a dam site across the Sacramento River near Red Bluff, California, in connection with a scheme to divert water for irrigation. The site is underlain by Recent Sacramento River sediments. These rest on poorly consolidated Tehama formation (Pliocene) alluvium, interbedded with Tuscan formation volcanic sediments, derived respectively from bedded marine formations of the Coast Ranges and the lavas and pyroclastics of the Cascade Mountains on the east. Methods of foundation and construction material investigation involving geology, hydrology, and soils mechanics utilized in the study are summarized, and the use made by the design engineers of the data thus provided is discussed briefly.

HIGH ROCK-CUT SHORE LINE AT CAVE ROCK, LAKE TAHOE, NEVADA

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Above the eastern shore of Lake Tahoe, on the south side of Cave Rock, is a short rock-cut shore line at an elevation of 6360 feet, or about 140 feet above the lake level. Well-rounded gravels and boulders extend from the level of Highway 50 up to the level of the two caves from which the prominent rock gets its name. These boulders are almost entirely andesite and are locally derived. Cave Rock is an intrusive plug of Kate Peak, hornblende-pyroxene andesite. The shore line consists of groove cut to a depth of about 2 feet and of pot holes several feet in diameter. It is probable caves are, in part, formed by wave action.

OUTLINE OF GEOLOGY OF SIBERIA

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The speaker briefly reviews evolution of ideas of geology of Siberia following the synthesis by E. Suess and L. DeLauncy, to present the latest concept of paleogeography of the country from Precambrian up to Quaternary, and to emphasize some outstanding features illustrated by general geologic and tectonic maps. For conclusion, as particular items of Siberian geology, there will be discussed: distribution and petrology of Siberian traps, young movements within old folded ranges, and new data on Siberian glaciation.

EXPERIMENTAL DEFORMATION OF CALCITE CRYSTALS

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Cylinders cut from single crystals of calcite have been deformed by compression and by extension, at 5,000 to 10,000 atmospheres confining pressure, at 20°C, 150°C, and 300°C. Shortening and elongation of between 5 and 18 per cent have been achieved in different experiments. This paper records stress-strain data for different conditions and summarizes evidence for various mechanisms of deformation as obtained from microscopic study of sections cut from the deformed material.

ENGINEERING GEOLOGY—UNION VALLEY DAMSITE, EL DORADO COUNTY, CALIFORNIA

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The U. S. Bureau of Reclamation has investigated the possibility of a 384-foot, earth-fill dam at Union Valley on the north fork of Silver Creek, a tributary of the South Fork American River.

Present in the area is the Sierran Bedrock Complex: the Calaveras formation (Mississippian ?) and Jurassic quartz diorite, as well as a Miocene series comprised of tuff, fluvio-lacustrine sediments, and andesite agglomerate. The Miocene series occurs as channel fills in a Cretaceous (?) land surface developed on the bedrock complex.

The present gradient and trend of the alluvium- and agglomerate-filled channel is southwesterly at 38 feet per mile. Attitudes in the sediments as well as the channel gradient show that during the Pleistocene uplift this portion of the Sierran block was tilted eastward rather than to the west.

Geologic problems affecting dam design included the elevation and course of an alluvium- and agglomerate-filled channel, permeability of the alluvium, and the development of suitable construction materials.

LARGE-SCALE THRUSTING IN NORTHERN SNAKE RANGE, WHITE PINE COUNTY NORTHEASTERN NEVADA*

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The northern Snake Range comprises a Precambrian complex, including gneiss, granite, schist, and schistose quartzite, with a Paleozoic sequence ranging from Cambrian to Permian, resting with thrust contact on the basement rocks. Locally Prospect Mountain quartzite occurs below the thrust.

The thrust plane occasionally truncates but is generally subparallel to structures within the basement. At the thrust occurs an intensely sheared, tectonically banded, and partially recrystallized limestone mylonite. Structures within the overthrust sheet are widely truncated by, though partially subparallel to, the thrust. Eastward imbrication is characteristic, and there are probably one or more major thrusts above the one here described.

Along both the eastern and western range fronts the flat thrust has been bent and locally downfaulted so that it passes underground into the adjoining valleys. This deformation is much younger than the thrusting; probably it is essentially contemporaneous with the tilting and faulting of the Cenozoic sediments exposed in the Sacramento Pass re-entrant.

The thrust underlies an area more than 40 miles north and south and 20 miles east and west

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within the range, but it extends beyond it. Farther west, in the Shell Creek Range and the southernmost Cherry Creek Mountains, similar thrusts occur which may be a continuation of the fault here described.

This thrusting of younger over older rocks is interpreted as part of a regional shearing-off plane. The Paleozoic sequence has moved eastward over the basement, piling up in subsidiary slices thrust sheets and folds, apparently under the impact of more deep-seated thrust masses from the west.

SILICIFICATION OF ORDOVICIAN FOSSILS IN UTAH AND NEVADA

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Trilobites are silicified in the Ordovician Pogonip group in outcrops scattered from southeastern Nevada (vicinity of Pioche) to northeastern Utah (vicinity of Logan) in a linear belt somewhat paralleling the geosynclinal margin. Replacement has been selective as only the calcareo-chitinous trilobite tests have been silicified, whereas associated gastropods and cephalopods are unreplaced, although brachiopods, Bryozoa, and ostracods are partially silicified in some places.

That the replacement was penecontemporaneous, rather than later replacement by ground-water action, is indicated by the following: (1) Only certain beds are replaced; (2) the silicification is not a surface feature but extends throughout beds irrespective of cracks, joints, or surface-weathering phenomena; and (3) the belt of Ordovician outcrops in which trilobites are silicified crosses from the semiarid Basin and Range province to the more humid Middle Rocky Mountains province suggesting that present climatic and weathering conditions have neither effected nor affected the silicification. Silicified trilobites have not been found to the east in Utah nor to the west in Nevada in Pogonip strata of the same general lithology and containing the same faunal assemblage. However, in central Nevada the opposite relation is found—the gastropods and brachiopods are silicified, and the trilobites are untouched.

Penecontemporaneous replacement may reflect nearness to shore under certain conditions; selectivity of replacement may be controlled by depth, temperature, salinity, and silica availability, and by differences in organic content of the tests of various organisms.

SIGNIFICANCE OF ROCK WEATHERING IN ENGINEERING GEOLOGY

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Weathering processes either weaken or enhance the engineering-physical properties of rock and soil; use of the material dictates the significance of this alteration. Weathering processes are widely discussed in the literature; however, the significance of rock weathering has received inadequate attention. Current research investigations were motivated by problems encountered in engineering geology.

The types of weathering processes are well known—the physical or *in situ* fragmenting and the chemical breakdown of constituents.

Factors affecting weathering include: parent material, mineral composition and compatibility, granularity, and inherent structure; climate; physiography; ground water, its composition and pattern of movement; time; and vegetation.

Problems of rock and soil weathering invariably confront the geologist dealing with: excavations; elastic rebound; tunnels; slope stabilization; adequate foundation, groutability, permeability, and ground-water movement; reservoir leakage and silting; and construction materials.

Megascopic and microscopic criteria for recognition of the degree of rock and soil weathering are based on studies of: texture; structure; color; mineral assemblage; chemical composition; and criteria of a negative nature. A correlation between the degree of weathering and the engineering-physical properties of rock and soil has been attempted for: geophysical properties; drilling, blasting, and loading characteristics; water-intake, permeability, and groutability; slope stability; adequacy for construction materials and foundation.

The significance of widespread rock weathering or minor geologic features such as weathered bedding planes, joints, and sheeted structures, and spheroidal weathering are commonly misinter-

preted or overlooked during exploration, resulting in expensive complications and design changes during the construction phase.

CENOZOIC IGNEOUS ACTIVITY, OROGENY, AND SEDIMENTATION NEAR LAS CRUCES, NEW MEXICO*

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Late Cenozoic time in the Las Cruces area was marked by intermittent but almost continuous faulting of diverse blocks. Valley fill over depressed blocks was supplied by erosion of uplifted masses and by recurrent volcanic activity.

Two series of pyroclastics and flows, an earlier group predominately of intermediate volcanics and a later rhyolitic group, were erupted in probable mid-Tertiary time. Intrusive rhyolite and monzonitic rocks occur as dikes, sills, and stocks. Elongate fault blocks were uplifted into mountains in late Miocene (?) time and, along with the volcanic piles, were the source of the late Miocene to early Pleistocene Santa Fe sandstones and siltstones. Some sandstone pebbles were derived either from distant highlands or from uplifts now buried. Basalt tongues and local conglomerate lenses are interbedded with the sandstones; the local conglomerates suggest individual discordant uplifts during Santa Fe time.

Widespread pediments cutting the Miocene to Pleistocene rocks are veneered by vertebrate-bearing sediments. Highlands were again raised, discordantly, along normal faults, and along a thrust fault. Subsequently, the Rio Grande came into existence and promoted local dissection of the pediments. The river, in surges of degradation and aggradation, developed terraces. Basalts of at leas two stages were extruded, in places on the river terraces. Faulting has continued until the present

SUGGESTED ORIGIN FOR CHAOS STRUCTURE

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Giant breccias and chaotically disordered strata have been described in many areas. In 1941 Levi Noble described a brecciated rock assemblage, shingled up on a Cyclopean scale, and called it "chaos". He said the chaos formed by the breaking up of the thrust plate above a thrust whose apparent minimum extent is 75 miles. Similar megabreccias of sedimentary or sedimentary-tectonic origin have recently been described, but these differ from the truly tectonic chaos in several important respects. The true chaos generally lack contemporaneous sediments, have a larger areal extent, maintain a crude stratigraphic sequence, are sheared rather than tumbled in appearance, and are seldom monolithologic.

An alternate origin for tectonic chaos may be by the imbrication and piling up of a whole series of very small thrust plates above an underlying block, which is shortening under compression. Strong, competent plates move out a few miles without being broken appreciably, but most plates break up into giant lenses that move much shorter distances. The most incompetent material may be ground up into a breccia or gouge, which then acts as a lubricant for the larger lenses and plates. As the chaos thickens, its increased strength and weight cause it to adhere to the underlying block and move forward, like a plow, into the section of thinner, undisturbed crust—causing this crust also to form a chaos. The stratigraphic section of the underlying block is thus "skeletonized" and abbreviated in the "chaos plate", but retains a crude stratigraphic order.

CORRELATION OF THE MAROON FORMATION IN THE CRYSTAL RIVER VALLEY, GUNNISON, PITKIN, AND GARFIELD COUNTIES, COLORADO

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Almost continuous outcrops of Pennsylvanian and Permian (?) rocks between Glenwood Springs and Crested Butte, Colorado, offer an opportunity for correlation of the type Maroon with more extensive outcrops to the north.

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Measurements of the Maroon formation from north to south are: Dry Park Ranch—7050 feet, Marion Creek—7037 feet (incomplete), Thompson Creek—4339 feet, Coal Creek—2333 feet (incomplete), West Sopris Creek—1100 feet (incomplete), Heuschkel Ridge—2508 feet, and Schofield Park—750 feet. The Weber sandstone and South Canyon Creek dolomite, observed near Glenwood Springs, are absent, and all the red beds below the Entrada sandstone are referred to the Maroon formation.

One thin unit of limestone and gray shale, traced from Dry Park Ranch to West Sopris Creek, is questionably identified at Heuschkel Ridge, but is absent at Schofield Park. Several similar limestones are present within the Maroon formation at Marion Creek and Dry Park Ranch, but disappear north of Thompson Creek. These units are too restricted in area to allow their use in formational classification. The Maroon and Gothic formations, as previously defined, are, therefore, recognized in this area.

Partial sections of the Gothic formation, measured beneath the Maroon, are as follows: Dry Park Ranch—330 feet, Thompson Creek—331 feet, West Sopris Creek—650 feet, Heuschkel Ridge—965 feet, and Schofield Park—500 feet. Gypsum, present in the upper Gothic north of West Sopris Creek, has resulted in striking flow deformation and solution brecciation.

SALTY GROUND WATER NEAR LINDSAY, CALIFORNIA

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Water wells near Lindsay, Tulare County, California, are restricted to relatively shallow depths by the widespread occurrence of sodium chloride ground waters that are injurious to local agriculture. Depending on the proportion of shallow and deep supplies, waters with 500–2600 ppm total dissolved solids and 30–90 per cent anion equivalents of chlorides have been produced.

Recent drilling of nine core holes and wildcat wells permits evaluation of hydrologic and geological properties of the sediments. They consist of continental interfan deposits, correlated partly with the Kern River-Chanac formations (Miocene to Pleistocene). Aquifers are thin, ill sorted, and have low permeabilities. Those in the upper section contain water of excellent agricultural quality. The salt-water sands are 200–900 feet deep and affect wells within an area of 65 square miles. In at least the southern part of the area, the shallowest salt water occurs in one widespread sand; little vertical "zoning" exists. A water sample from the salty beds contained 1800 ppm (or 97 per cent) chloride and 3600 ppm total solids.

Water-quality and stratigraphic studies indicate that these waters are petroleum brines that originated in Tertiary brackish-water and marine sediments and are now contained in their continental equivalents.

HYDROLOGIC METHODS USED IN LOCATING THE CASA LOMA FAULT

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The Casa Loma fault is marked by a sinuous, irregular scarp in the northern part of the Perris block in western Riverside County, California. Hydrologic methods used in proving the existence of this fault and locating it are of considerable interest.

Physiographic evidence of the existence and location of the fault includes (1) the scarp; (2) two horst blocks or fault slivers; (3) sags; and (4) apparent change of the course of the San Jacinto River. Hydrologic evidence of its existence and location includes (1) difference in water levels; (2) difference in pattern of both daily and seasonal recovery after drawdown; (3) difference in quality of water; (4) presence of springs.

Observation of the Casa Loma fault in a recent excavation shows that near the ground surface it

is a dip-slip fault dipping about 45° NE. Its Recent activity is indicated not only by the physiographic evidence but by the fact that it acts as a barrier to shallow as well as deep ground water. Complexity of the fault pattern is indicated by both physiographic and hydrologic evidence.

This fault is apparently related to the San Jacinto fault, approximately parallel to it and, 2 to 3 miles southwest of it, to other faults of the San Jacinto Mountain block, and to fracture systems in the crystalline rocks of the Perris block.

ORIGIN OF THE HOLLADAY SPRINGS, SALT LAKE CITY, UTAH

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A group of springs issues from the margin of a bouldery alluvial fan on the piedmont at the border of the Wasatch Mountains 9 miles southeast of Salt Lake City. These springs are the municipal water supply for Holladay, a suburb of Salt Lake City.

A proposal to divert water from near-by Neff Canyon would dry up 3000 feet of the natural channel. Since the source of the Holladay springs was unknown, would this proposed diversion have any effect upon the springs? Investigation disclosed that the abnormally large and wide seasonal fluctuation in the flow of the springs was not typical of ground water issuing from alluvium. An engineering and geological study revealed that: (1) the surface runoff from Neff Canyon is both unusually short in duration and abnormally small in amount for the size of the watershed; (2) the peak discharge from the springs coincides with the peak surface flow of Neff Creek; (3) the principal flow of Neff Creek is underground cavern flow through limestone along a major thrust zone, the outlet being masked by bouldery alluvium; (4) fluorescein dye introduced in the stream channel in Neff Canyon appeared in the Holladay Springs after 27 hours, having traveled a horizontal distance of 2.5 miles.

SEDIMENTATION IN GARIBALDI LAKE, BRITISH COLUMBIA

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Garibaldi Lake, in the southern Coast Mountains, is distinctive in its great depth (849 feet) for its size (1 by 3 miles). Most of the water and nearly all the sediment that enters it come from near-by glaciers, and as a high proportion of the water is lost by underground percolation virtually all the sediment is trapped in the lake. Soundings indicate an irregular platform, the extension of the late Pleistocene lava dam, at the lower end of the lake, and a deep central basin shoaling gradually toward the upper end but bounded by steep (25° to 45°) lateral walls. The platform is covered by homogeneous brownish clays with a regular though indistinct stratification. The basin floor is covered with olive-gray silt containing a subordinate but significant sand fraction. Graded beds, ½ to 3 inches thick, are conspicuous. Sandy and stony material floor the upper end of the lake.

The clay of the platform has evidently been deposited from a relatively still suspension, but the coarser deposits of the basin floor appear to have been laid down by intermittent turbidity currents. Turbidity currents may also account for an inverted temperature gradient in the deeper waters.

INTERPRETATION OF GRAVITY ANOMALIES IN COYOTE VALLEY, CALIFORNIA

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Coyote Valley, a roughly oval depression of 100 square miles, lies between the Calico Mountains, Paradise Range, and Alvord Mountains in the central Mojave Desert, San Bernardino County, California.

Bedrock exposed on three sides of the western half of the valley consists of Paleozoic metamorphic rocks (average specific gravity 2.8) intruded by Mesozoic (?) gabbro (3.2), diorite (2.8), and quartz monzonite (2.7). Clear surface evidence of faults bounding the valley is lacking.

Gravity observations at 151 stations in the western half of the valley provide the basis for a Bouguer anomaly map covering 40 square miles. A field of negative Bouguer anomaly covers most of the alluviated area studied. A steep and fairly straight gravity declevity along the northwest edge of the valley separates the negative area from a positive area to the northwest. A 6.5 milligal negative minimum occurs 3.5 miles northwest of the topographic center of the basin. At the south edge of the valley a second area of positive anomaly reaches a maximum of 8 milligal.

The positive anomaly at the southern edge of the valley is presumably an effect of buried basement rocks of excessive density. The steep gravity gradient along the northwestern margin of the valley apparently marks the trace of a concealed Pliocene (?) fault. Thick alluvial fill on the downthrown (valleyward) side of the fault results in the negative anomaly.

The gravity data suggest that Coyote Valley exists partly because of faulting, a conclusion that could not be reached from the surface evidence alone.

SHEAR ZONES OF THE NORTHEASTERN PACIFIC OCEAN AND ANOMALOUS STRUCTURAL TRENDS OF WESTERN NORTH AMERICA

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Four great topographic trends, three escarpments and a trough, have been discovered under the northeastern Pacific Ocean. The trends approximate great circles, are subparallel, and are uniformly about 600 or 1200 miles apart. From north to south, approximate positions and dimensions are:

(1) (Mendocino Escarpment) 5000 feet high, 1400 miles long
(2) Between southern California and the central Hawaiian Islands, an escarpment 4000 feet high and 1600 miles long
(3) west of the Revilla Gigedo Islands, a narrow trough 2000 to 5000 feet deep and 1800 miles long
(4) between Christmas and Clipperton islands, an escarpment 1000 feet high and 3300 miles long.

These wholly submarine trends (as numbered above) appear to have the following continental extensions in east-trending structures which are anomalous relative to the generally northwesterly trends of western coastal North America:

(1) a major east-trending gouge zone; southern limit of Cascade volcanoes
(2) Channel islands; transverse ranges; northern limit of block-faulted continental borderland
(3) east-trending Revilla Gigedo Islands and volcanoes of central Mexico; southern limit of continental borderland; northern limit of Acapulco Trench and associated volcanoes and earthquakes
(4) southern limit of Acapulco Trench and associated structures.

The trends mark great shear zones. Between each pair of shear zones the crust appears to be deformed as a block, and alternate blocks appear to be compressed and stretched. This deformation is theoretically possible even though the shear is produced by uniform compression, and equal displacement occurs on the shear planes.

Possible origins are discussed.

ACCURATE IDENTIFICATION OF FOSSIL LEAVES

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Recently, Dr. Adriance Foster of the University of California has studied the minute details of living leaves by rendering them transparent and mounting them in plastic on glass slides. Utilizing this method, the present writer has completed a study of the leaves of 90 taxa of living representatives of the Betulaceae (birch family) from all parts of the world.

One hundred fifty characters in 350 specimens were studied microscopically and macroscopically. Selected taxa were sampled extensively. Eight of the 150 characters were found very important in leaf identifications in the Betulaceae. These characters are: nature of the midrib, the leaf margin, the lowest secondary veins, secondary vein endings, the leaf base, the pattern of the tertiary veins, the

angle of departure of tertiary veins from larger veins, and the distribution and appearance of the minor or net vein endings. Certain measurement ratios were also found helpful.

Five fossil leaf taxa were studied, too few to permit more than tentative conclusions regarding the usefulness of Foster's method. Use of the characters mentioned, in combination with lesser characters, enabled the writer to identify accurately the five fossil taxa, of which some had been misidentified. This study showed that comparisons of fossils with transparent slides of living taxa is a much more accurate method of identification than comparison with leaves on herbarium sheets. Future studies should employ extensive use of these slides to insure reliable determinations of fossil leaf genera and species.

GEOLOGIC HISTORY OF THE SAN NICOLAS ISLAND REGION, CALIFORNIA

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The oldest rocks known from the San Nicolas Island region are Middle Eocene and include more than 2000 feet of marine sandstone and shale exposed on the island plus an indeterminate additional thickness of the adjacent sea floor. An erosional interval following Eocene deposition was terminated in Middle Miocene by deposition of marine sediments resembling those of the mainland Monterey formation. Middle Miocene sedimentary rocks are known only from the insular shelf; none are exposed on the island proper. Volcanic rocks, also believed to be Miocene, are present on the island and its shelf. Pliocene rocks do not occur in the San Nicolas region, indicating that erosion was in progress then. Geologic evidence indicates that the folding and faulting at the close of the Pliocene was followed by submergence of the island. There are, however, certain zoologic objections to such submergence.

Several marine terraces were developed on the island as it emerged from the Middle Pleistocene sea. Occurrence of abundant metamorphic pebbles on these terraces without a plausible source on the island suggests a near-by Pleistocene landmass. Subsequently, lower world-wide sea levels, associated with Pleistocene continental glaciation, permitted the erosion of several additional benches below modern sea level. Present topography of the island has been created by stream and wind erosion since the Middle Pleistocene.

LEONA RHYOLITE, ALAMEDA COUNTY, CALIFORNIA

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The Leona (soda) rhyolite crops out discontinuously for 21 miles along the front of the hills from Hamilton Gulch, Berkeley, to 4 miles southeast of Hayward. Long ago, Lawson and Clark agreed that it represents a single extensive lava flow of Pliocene age or older. Because so many large rhyolite extrusives are now being interpreted as welded tuffs, re-examination of the Leona is timely.

In its southern half, recently studied, the formation exhibits spherulites, vesicles, and phenocrysts, and lacks pyroclastic debris—all suggesting origin as lava. However, downward extension of several broad hill cappings into narrow feederlike masses, presence of rhyolite dikes near by, and other features suggest emplacement as a series of domes and short flows rising along subsidiary shears in a major fault zone, rather than as a single flow.

Commonly, the rock is a weathered mixture of iron-oxide stained quartz and argillized feldspar. Where fresh, it typically contains a few corroded phenocrysts of sodic plagioclase and quartz in spherulitic glass or in a felted microcrystalline groundmass of quartz, untwinned albite, and subordinate orthoclase. A little chlorite and altered biotite are the only ferromagnesian minerals. Pyrite crystals, generally corroded, are abundant in fresh rhyolite but extremely rare in the underlying rocks; the pyrite may be primary.

The formation is deeply eroded, little deformed, and overlain by pre-Recent sediments. This and other indirect evidence favors early Pleistocene age.

Study of the formation's geologic history helps to develop a detailed picture of Quaternary events in the East Bay, particularly drainage changes.

PROGRESS REPORT ON A TEST FOR EXTRUSION FLOW IN THE MALASPINA GLACIER, ALASKA

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Malaspina Glacier, a piedmont ice sheet covering more than 1000 square miles on the flat coastal plain of southern Alaska, affords ideal conditions for testing Demorest's hypothesis of extrusion flow. In 1951 a 2-inch vertical hole was bored by an electrical hot point to a depth of 1000 feet near the center of this glacier. Seismic reflections show that the glacier here is 1950 feet thick and that its floor, nearly 600 feet below sea level, slopes gently northward against the southward flow of the ice.

Initial orientation of an aluminum pipe in the bore hole was determined by an inclinometer survey. A resurvey in 1952 recorded deformation during the first year. No measurable differential flow took place in the uppermost 300 feet of the glacier, but below that depth flowage occurred at a low but uniform rate except for a slight acceleration below 900 feet. Total differential flow between top and bottom of the 1000-foot pipe was only 5.75 feet. The absolute movement is not known, as the test site is too far from fixed reference points.

The deformation is, as yet, too slight to permit firm conclusions. However, the results suggest that the surface ice is carried along by the flowing ice beneath in a manner contrary to the mechanism of extrusion flow. This test, a similar one in the Alps, and theoretical analyses throw great doubt on the validity of the extrusion-flow concept.

The work was supported by the Artic Institute of North America and the Office of Naval Research under contract N6onr 244-16.

COLLAPSE ORIGIN OF THE DIATREMES OF THE NAVAJO-HOPI RESERVATION

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About 250 diatremes are scattered over the Navajo-Hopi Reservation. The diatremes are associated with flows and tuffs of Pliocene age that rest on a surface of low relief. This surface is preserved in parts of the Hopi Buttes and Chuska Mountains but has been removed in the northern Navajo Reservation. The diatremes are funnel-shaped volcanic vents that flare to a width of a mile or more at the level of the Pliocene surface onto which they erupted. They range from an eighth to half a mile in diameter where they are exposed at depths of 1000 to 2000 feet below this Pliocene surface.

A wide variety of material fills the diatremes; the material found at any one exposure depends largely on the stage of development of the diatreme and the level of exposure. In its upper part a fully developed diatreme is filled with tuff and limestone, and locally with varved clay, evaporites, and some bedded chert. Lower in the vent these sediments give way to tuff, breccia, huge blocks of country rock, and finally agglomerate and solid igneous rock. Much of the tuff filling, which in some vents is at least 2000 feet thick, is well bedded and shows many features of fluviatile deposition, such as cross-lamination, channels, and unconformities. The dips of the beds steepen with depth and are commonly vertical and intensely deformed in the deeply eroded vents. In some vents the bedding is obscured, in part by shearing along close-spaced thrust faults. A vent, so filled, can have originated only by progressive subsidence or collapse.

Successive stages of collapse are exemplified by some of the diatremes of the Monument, Red Rock, and Chuska valleys.

GALAPAGOS ISLANDS REGIONAL BATHYMETRIC TRENDS

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Between the Galapagos Islands and Ecuador is an elevated portion of the sea floor which rises to less than 800 fathoms and has an east-west trend. The area rises in a gentle arch from south to north, but an escarpment 600 fathoms high is present at one place along the north slope. The Peru Trench

extends northward along the coast of Ecuador and appears to transect the arched area, separating it bathymetrically from the Ecuadorian bulge in South America. This suggests that the elevated sea floor existed prior to the development of the trench.

The subsea ridge upon which Cocos Island is situated, which extends west-southwestward from Panama toward the Galapagos, is shown to extend for at least 500 miles west of the Galapagos. This ridge is topographically rugged, with numerous seamounts upon it, and is quite unlike the arched area west of Ecuador. An emergence of the ridge in the geologic past could have facilitated floral and faunal migrations to the Galapagos, but evidence of emergence, as would be shown by guyots along the ridge, is yet to be discovered.

The east-west trends of the Galapagos region tie in with the elevated area extending east and somewhat north from the Tuamotu Archipelago. This system is subparallel to the four structural trends which lie off North America and, like them, approximates a great circle.

GEOLOGY, GEOPHYSICS, AND WATER YIELD NEAR SANTA FE, NEW MEXICO

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The Santa Fe area is on the east margin of the Rio Grande structural depression. The southern Sangre de Cristo Range, largely Precambrian rocks, is the uplift bordering the plains of the depression in this latitude. Surface runoff originates largely in these mountains; both surface and ground-water discharge is to the Rio Grande. The base flow of perennial streams is sustained by ground water from drift in mountain cirques, and from ground water in the Santa Fe group (terrestrial Plio-Pleistocene clastics) discharging at the west margin of the plains. This major aquifer laps onto the eastern uplands and onto a lower structural platform of early Tertiary rocks lying south of Santa Fe. This platform impedes normal movement of ground water toward the south.

Water-table contours showed large changes in the transmissibility of the major aquifers locally, indicated locations of covered normal faults, suggested areas for other types of geophysical tests, and identified areas for obtaining large ground-water supplies.

Only one-third of the annual water yield in the area south of Santa Fe is contributed from the upland border there; the unit yield is 0.7 inch in the upland and 0.5 inch on the plains. Nearly all the latter yield is ground water. Probably two-thirds of the water yield north of Santa Fe is from the higher mountains there, where the unit yield ranges from 2.0 to 5.8 inches, depending upon altitude. Consumption by evapo-transpiration averages about 17 inches in the mountains and 13 inches on the plains.

ORIGIN OF PLAYA STONE TRACKS

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Curious tracks on playas, obviously made by moving stones, have been interpreted in recent accounts as caused by wind blowing stones over level clay when water lubricated. Stones weigh from ounces to several hundredweight.

Among hundreds of tracks on Racetrack playa, Inyo County, California, certain grouped, similar ones exhibit neo-parallelism which implies unit movement of scribers; precise measurements and plots confirm this. Certain bends and cusps in these irregular tracks are identifiable with analogies in other tracks of the same set; although not identical, the lines have the same "signature". A transparency plot of analogous points (one for each track in same signature group), when moved along plotted tracks, matches repeatedly at other sets of analogous points. This proves unit movement of (small) scriber stones. Some rotation accompanied linear movement and precluded true parallelism of tracks and identity of length and shape. Distance of unit movement exceeded 200 feet, and maximum spread of stones in unit is 270 feet.

Unit movement over so great a span scarcely allows, for the tracks surveyed, any reasonable conclusion as to motivation other than wind-blown ice floes dragging protruding stones. Ice ramparts and other evidence of ice push are manifest and indicate here longshore shearing motion, feasible for ice floes but impossible for ice shove by thermal expansion.

The writer finds no evidence that stones, freely wind blown, have made any tracks. Though not disproved, this idea meets serious objections in many other small-object tracks than those surveyed, and seems fantastic for tracks inscribed by 300-pound stones.

SEDIMENTARY PATTERNS AND URANIUM MINERALIZATION IN THE MORRISON FORMATION OF THE COLORADO PLATEAU

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Specialists in many fields have investigated the uranium deposits of the Salt Wash sandstone member of the Morrison formation. In spite of concentrated study the problem of genesis is still unsettled.

It is generally believed that the Salt Wash is a fluvial deposit made up of coarser fractions deposited in the channels and finer fractions deposited on the flood plains. The ore deposits occur in the sandstone lenses usually in association with fossil vegetation. Most ore bodies contain elongate masses of higher-grade material which are called "rolls"; fossil logs, when present, lie parallel with the associated rolls.

The current directions which prevailed during the deposition of the sandstones can be determined through mapping of cross-lamination and other primary features. Detailed study of the ore bodies made in certain districts show that the rolls lie mostly parallel with the direction of flow of the depositing streams as revealed by cross-lamination. This is thought to mean that the subsurface solutions which brought together the various constituents of the ore traveled through the sand lenses in essentially the same patterns and directions as the original surface streams. Other problems such as the ultimate source of the constituents of the ore and the time of mineralization may also be solved by aid of sedimentary studies.

CRYSTALLOGRAPHIC CONTROL OF REPLACEMENT OF QUARTZ BY FELDSPAR

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Quartzite immediately adjacent to the disseminated copper ore body at Bingham, Utah, has been replaced by orthoclase along the quartz grain boundaries. The crystal structure of the quartz has governed the position of the feldspar replacement resulting in partially replaced quartz grains which show a crystallographic outline. Measurements of these faces employing Universal stage technique reveal that the $(10\bar{1}1)$ r or z, and $(2\bar{1}11)$ s or s′ are the largest and most abundant forms. Dissolution of irregularly shaped crystal fragments sometimes produces well-developed definite faces, and it is suggested that there might be some similarity in this dissolution phenomena and replacement along preferred crystallographic directions.

SOME TRANS-PACIFIC PALEOZOIC CORRELATIONS

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This paper is confined to discussion of post-Cambrian correlations between Australia and North America. Most interesting discoveries in Paleozoic geology in Australia concern widespread occurrence of shelly Ordovician faunas. The nonendemic portion of early Ordovician (middle and upper Canadian) faunas is overwhelmingly of North American affinities. Middle and Upper Ordovician faunas are of general north Pacific-Arctic aspect. Some evidence supplied by the planktonic graptolites is in harmony with distribution of shelly faunas.

Silurian faunas are not well known but are probably largely endemic, except for the graptolites which point toward Europe.

Lower Devonian faunas of Victoria, Tasmania, and New Zealand form a closely knit unit of European affinities. Middle and Upper Devonian faunas of Australia are likewise predominantly European, with some significant exceptions (*Sphaerospongia, Koeneniles*) which point to North America.

Australian Mississippian faunas are only gradually becoming known, and only preliminary con-

clusions are possible. Some faunal correlations with North America appear probable. After the Mississippian there are no clearly recognizable faunal links between Australia and North America. There is no marine Upper Carboniferous (Pennsylvanian) in Australia. In the Permian we have two distinct faunal provinces: (1) a western Australian one of wholly Tethyan aspect, (2) an eastern Australian one which has a predominance of endemic forms, intermingled with some Tethyan elements.

The evidence supplied by the Paleozoic faunas is consistent with assumption of existence of intermittent land masses or island chains in the northern and central Pacific until about the end of Mississippian time.

GLACIATION AND UPLIFT ALONG THE NENANA RIVER, ALASKA

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Four glacial advances have been recognized on the Nenana River. Deposits of the earliest advance are granite erratics about 500 feet above the river near Browne and 2500 feet above the river near Lignite Creek. Deposits of the second advance include outwash gravel 600 to 900 feet above the Nenana River, varved clay, and patches of till. Deposits of the third glacial advance include a terminal moraine about 450 feet above the Nenana River near Healy, outwash gravel, scattered lateral moraine ridges, and till. During glacial retreat a lake in the gorge between McKinley Park station and Healy was filled with sediments, after which the river was superposed on the bedrock wall of the sediment-filled gorge. Deposits of the fourth glacial advance include a terminal moraine at Riley Creek near McKinley Park station and well-preserved lateral and ground moraines. Outwash from the fourth advance rests unconformably on the lake deposits of the third stage. Slope and altitude of the glacial deposits suggest a northward tilting of about 25 feet per mile between the first and second advances, and 17 feet per mile between the second and third advances, with total uplift at Healy of more than 1000 feet.

GEOLOGY OF SOUTHERN EL SALVADOR, CENTRAL AMERICA

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Southern Salvador consists of Pliocene and younger volcanic rocks. A great east-west structural trough, formed by collapse of the crest of a gentle geanticline, traverses the region. South of it lie seaward-tilted fault blocks composed mainly of Pliocene andesites and basalts; in the opposite direction are coeval and similar rocks that dip northward, cut by many fault scarps. Most of these Pliocene lavas and tuffs were discharged from volcanoes now concealed beneath the floor of the median trough.

Since the trough was formed at about the close of the Pliocene, much of it has been filled by growth of large andesitic and basaltic cones many of which have been active within historic time. But parts of the trough persist in the Gulf of Fonseca, the Zapotitan Basin, and the huge bowl that holds Lake Ilopango.

In and near Lake Ilopango, Pleistocene and later volcanism was marked by protrusion of many dacite domes and by repeated discharge of glowing avalanches of dacite pumice and ash. After the original trough had been almost filled by these materials, large-scale engulfment formed a new trough. Subsequently this was filled by fluviatile pumice, by new domes, and by other pumice-avalanche deposits. Finally, within the last few thousand years, another engulfment occurred, forming the present lake basin inside which still another series of dacite domes developed, the last as recently as 1880. The region continues to be among the most active seismic zones of Central America.

TECTONIC MAP OF CANADA, 1950

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The probability of a fault through the Strait of Bell Isle is questioned. The direction of the dip of the beds on Anticosti Island is south, not north as shown on the map. Likewise the downthrow of the fault at the Hollow, Antigonish County, Nova Scotia, is north not south as shown.

In British Columbia, the coast synclines are all omitted; these include the Strait of Georgia, Juan de Fuca Strait, and the Fraser River Valley. In consequence the Upper Cretaceous coal basin of Vancouver Island and the Tertiary basin of the lower Mainland are omitted. The other coal basins of British Columbia are also omitted.

The structure contours on the Cretaceous formations of the Peace River area of British Columbia require general revision.

PACIFIC COAST SECTION (PS)

CLASSIFICATION OF CLYPEASTROID ECHINOIDS

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Studies of echinoids commonly referred to the Order Clypeastroida, based on morphology and structure as well as ontogeny, indicate that the order is polyphyletic. One group (Clypeastroida restricted), including Clypeastridae and Arachnoididae, is characterized by: compound plates in petals; interambulacra discontinuous on oral surface and narrower than ambulacra at ambitus, terminating adapically in a pair of plates; and separate auricles. Range late Eocene to Recent.

The second group, including the Laganidae, Fibulariidae, and a new neotropical family similar to Laganidae, is characterized by: simple or compound plates in petals; continuous narrow interambulacra terminated adapically by a single plate or series of single plates; and fused auricles. Range Senonian to Recent.

The third group, essentially Scutellidae *auctores*, including several groups elevated to rank of families, is characterized by: petals with simple plates; interambulacra on oral surface varying from narrow to as wide as ambulacra at ambitus, discontinuous or not and terminated adapically by a pair of plates; and fused auricles. Range lower Eocene to Recent.

The last group, Rotulinae or Rotulidae *auctores*, is characterized by: petals with simple plates; continuous interambulacra about as wide as ambulacra at ambitus, terminated adapically by a series of single plates; fused auricles; and 20 (instead of 15) basicoronal plates. Range Miocene to Recent.

Much homeomorphy is present between species not closely related and necessitates the proposal of a number of new generic names.

CRETACEOUS TERRESTRIAL VERTEBRATES FROM COLOMBIA, SOUTH AMERICA

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In 1949 R. W. Fields obtained a small collection of fossil vertebrates from sands and clays near the town of Ortega, Department of Tolima, Colombia, South America. The specimens bear the number 39650 in the collection of the Museum of Paleontology, University of California, Berkeley, California.

Two types of crocodilian teeth are preserved. Some with pronounced longitudinal ridges and grooves are like teeth of some living alligators and large crocodiles; possibly they represent an ancestral caiman. The others are blunt, conical, and curved with subdued longitudinal striations better developed on the inner surfaces. Their affinities are not clear. All crocodilian vertebrae collected are amphicoelous, and one bears a heavy hypopophysis with an elongate base analogous to *Hyposaurus*. Two presumed carnosaur teeth are similar in size and form to smaller teeth of some Upper Cretaceous deinodonts from North America. They lack the attenuation characteristic of most sebecosuchian teeth. A few lepidostean scales were also collected.

This assemblage is of early Tertiary or Cretaceous aspect. If the carnosaur teeth are correctly referred the other specimens tend to support them in favoring assignment of a Cretaceous age. They are the first Cretaceous terrestrial vertebrates reported from Colombia.

LONGIROSTRINE CROCODILIANS FROM THE TERTIARY OF SOUTH AMERICA

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Tertiary longirostrine crocodilians are uncommon in South America; the four described species are based on fragmentary material from Brazil and Argentina. They have been assigned to the Gavialidae and Tomistomidae (or Crocodylidae), but most workers outside South America have tacitly preferred the latter disposition.

Two incomplete skulls of a small gavialid (*?Gavialis* s.l.) from Oligocene beds near Coyaima, Colombia, in the collection of the Museum of Paleontology confirm the early presence of the family in South America. As in *G. browni* (L. Pliocene, India) the palatine fenestrae are longer, the nasals longer, the face lower and longer than in the living species. Inflation of the pterygoid bullae is evident but not pronounced, orbital rims are characteristically expanded, and the palatines are parallel-sided. Fragmentary rostrae from the La Venta Miocene may also pertain to gavialids.

Tomistomids from the La Venta Miocene are known from jaws similar to the cosmopolitan Miocene species of *Gavialosuchus*. A small mandible with outstanding alveolar "pedicles" recalls *Euthecodon* (later Tertiary, North Africa), but may be a case of convergence.

The Tomistomidae were widespread during the Tertiary; their presence in South America was to be expected. Hitherto, however, Gavialidae have been definitely identified only from the Old World. Their early presence in South America revives questions of centers of origin and dispersal. Since the group is better adapted to an aquatic existence than other eusuchians, dispersal by oceanic routes appears possible. Absence of the family from North America, if genuine, is difficult to explain, but several other eusuchians and the Sebecosuchia also seem never to have lived here.

SOME LOWER EOCENE CORRELATIONS ON THE PACIFIC COAST

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The occurrence of the orbitoidal foraminifer *Aktinocyclina aster* Woodring and the reef coral *Astreopora sanjuanensis* Durham in the "basal *Spiroblyphus* sands" at Media Agua Creek in the San Joaquin Valley, California, and in the Crescent formation of Washington points to the correlative age of these strata.

Other evidence corroborates the above correlation and points to an equivalence in age of the Sierra Blanca limestone of the Santa Barbara Coast and the Mabury Reef sandstone of the San Joaquin Valley in California, and the assignment of all these units to the Lower Eocene ("Capay").

INVITATION TO STUDY SILICOFLAGELLATES

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The Central California Upper Eocene Kellogg shale contains at least 41 species of silicoflagellates some of which are so arranged that they resemble an Oppelian zone. Seven species appear for the first time, and three other species become extinct. These two groups of species ranges overlap stratigraphically in such a way that six species are restricted to the zone of overlap. This arrangement was not designated as an Oppelian zone because duplication of this work in other localities is lacking.

In the Central California Upper Eocene Sidney shale there are at least 27 species of silicoflagellates. No overlap of species ranges was apparent in the Sidney shale, but four species do have restricted ranges.

These facts plus the geographic distribution and simple morphology of the silicoflagellates indicate that these organisms might have significant geologic value.

ARCHAEOCYATHA FROM THE LOWER CAMBRIAN OF INYO COUNTY, CALIFORNIA

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The paper describes a collection of Archaeocyatha from the Lower Cambrian of Bishop quadrangle, Inyo County, California. The collection contains the following species: *Ajacicyathus nevadensis* (Okulitch), *Ethmophyllum whitneyi* Meek, *Pycnoidocyathus* sp., *Syringocyathus* n.sp., *Archaeocyathus atlanticus* Billings, *A. yavorskii* (Vologdin), *A.* n.sp., *A.* sp., *Protopharetra dunbari* Okulitch, *P.* sp., *Archaeopharetra*—type spitz.

The genus *Syringocyathus* is reported for the first time in North America.

SYSTEMATIC POSITION OF ARCHAEOCYATHA (PLEOSPONGEA)

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The affinities of Archaeocyatha to the Coelenterata and the Porifera are examined and discussed. It is concluded that the anatomy of Archaeocyatha is unlike that of the Coelenterata since they do not posses a mouth, coelenteron, nor mesenteries. Similarly there are basic differences between the Archaeocyatha and the Porifera. The sponges never possess parieties (septa) or the true laminar inner and outer walls. The spicular skeleton of the Porifera is also entirely different from the granular-laminar one of the Archaeocyatha.

It is suggested that the Archaeocyatha (Pleospongea) should be placed in a phylum of their own, and that the name Pleospongea, suggestive of affinities to the sponges, be dropped in favor of Phylum Archaeocyatha. It is regarded as obvious that neither the size nor the life span of a phylum is of any importance as far as the general scheme of classification is concerned.

AGE OF THE "DEVONIAN" OF THE KEARSARGE AREA, CALIFORNIA

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Recent studies in the Inyo Mountains of the beds assigned to the Middle Devonian by Stauffer (1930) show that they contain faunal elements that preclude a Devonian age assignment. The section 3 miles east of Kearsarge, composed largely of limestone and some calcareous shale, contains *Conchidium*, *Pycnostylus guelphensis* Whiteaves, and *Atrypina* cf. *A. disparilis* (Hall). New and better material shows that the *Calceola* of Stauffer's report is *Rhizophyllum*, a genus characteristic of the Silurian. The limestones of the Kearsarge section interfinger with and are largely replaced by arenaceous and calcareous shale to the north. This shale facies contains a large monograptid fauna with such characteristic Silurian species as *Monograptus nilssoni* Barrande, *M. tumescens* Wood, and *M. crinitus* Wood. These fossils indicate a late Niagaran or early Cayugan age for the beds. No faunas of Devonian age have been found in this area.

FORTY YEARS OF PALEONTOLOGY

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The Twelfth International Geological Congress, held in Toronto, Canada, in 1913 coincided with the close of an era in human history.

The day of the great monographs on the megafossils was drawing to an end, along with the day of the great empires.

With the war effort came a greater application of Paleontology to human problems, and technical advances in drilling and sample taking stimulated micropaleontology beyond all expectation. Paleontologists in general have come out of the cloisters of State and Federal surveys and college laboratories and are housed in ever-increasing numbers under the eye of oil executives.

All credit is due the persistent researchers who carry on the fundamental investigations into the life of the past—plant, invertebrate, vertebrate, megafossil, microfossil. May the scientific studies of historical geology still continue, strong and constructive—paleoclimatology, paleogeography!

The paleontologist is surely coming into his own!

OBSERVATIONS ON THE FORM OF THE PRINCIPAL SEISMIC IMPULSE

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It is a fairly common observation that two or more earthquakes of the same size, occurring at or near the same focus, nearly always produce identical seismograms. From this observation it may be concluded that the wave shape at the source is some very simple form of impulse and that the great complexity of most seismograms is produced by propagation complexities of the transmission medium. The various physical effects encountered in transmission, such as scattering, wave-type transformation, dispersion, coupling, etc., greatly modify or obscure the original wave form to such an extent that in the majority of recordings it is not recognizable.

There are a few transmission conditions in which the basic impulse form is maintained sufficiently well to be clearly recognized. A number of seismograms representing such favorable conditions will be shown. These range from small aftershocks of the Arvin-Tehachapi earthquake, showing impulses of approximately $\frac{1}{6}$ second duration, to a large impulse on a seismogram of the Kamchatka earthquake of November 4, 1952, having a duration of approximately 70 seconds.

In general, the observed wave forms conform approximately to the shapes predicted theoretically by Norman Ricker.

PROGRESS REPORT ON CAPACITY-TRANSDUCER SEISMOGRAPHS

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Development has continued on the capacity-transducer seismographs described in previous reports. Means have been provided for adjusting the periods of both the vertical- and horizontal-component seismometers. Modifications in the crystal-oscillator circuit have been introduced to improve the output-level stability so that the gas-regulator tubes in the anode-power supply have been eliminated. A new stylus has been designed for the hot stylus recorder which permits operation with Sanborn paper on ordinary seismograph drums rather than with the continuous belt described earlier. The recording line competes favorably with the best photographic recorders. A cathode-ray tube film recorder has been adapted for transcribing the magnetic-tape recordings to ordinary seismogram form.

VERY LONG PERIOD G WAVES AND AN UNIDENTIFIED WAVE OBSERVED WITH A THREE-MINUTE PERIOD STRAIN SEISMOGRAPH

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An electromagnetic linear-strain seismograph having a galvanometer of 3 minutes period and low magnification has been in operation for some months at the Seismological Laboratory. As a result of its unusual period response characteristic, the seismograms appear very different from those of shorter-period instruments. Body waves and surface waves having periods up to approximately 20 seconds which dominate seismograms of conventional instruments are relatively inconspicuous, whereas in this combination the largest amplitudes are exhibited by impulses with periods ranging from 1.1 to approximately 8 minutes. These include mantle Rayleigh waves (which will be reported in another paper by Ewing and Press) and mantle Love Waves known as G waves. In the seismogram of the Kamchatka earthquake of November 4, 1952, an unidentified wave having periods of approximately 2.8 and 2.25 minutes was clearly recorded. Its travel time corresponds with that of a Rayleigh wave excited at the antipodal point.

UNUSUAL RAYLEIGH WAVES FROM EXPLOSIONS

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In the course of some experimental seismic work carried on in West Texas by the Magnolia Petroleum Company, two types of Rayleigh waves were recorded which exhibit characteristics not ordinarily observed in Rayleigh waves from shot-hole explosions or from earthquakes. One wave, observed only from shallow shots, consists of two or three cycles traveling without dispersion at a relatively high frequency. This is believed to have traveled mainly in a thin limestone surface layer underlain by lower-speed sand and gravel. The other wave, most conspicuous from deep shots, appears as a dispersive train having periods that increase with time on the record, just the opposite of the sequence ordinarily observed. It is shown that, because of an unusually thick surface layer, the low-frequency cut-off of the instrumental system is on the high-frequency side of the group-velocity minimum. Thus, observable Rayleigh waves must lie along the high-frequency branch of the dispersion curve, and the group velocity would be expected to decrease with period in the manner observed.

STORM MICROSEISMS AND STORMS

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Heavy microseisms which are undoubtedly associated with storm conditions off the coast of Alaska disturb the Sitka Seismograph Station intermittently through the winter months. There is no apparent evidence that the microseisms are associated with conditions near the storm center because the storm often abates and the storm front often has passed over Sitka several hours before the microseisms appear. This supports the ocean swell idea of microseismic generation—the swell often travels at a slower rate than the front. Seven- to 10-second west coast microseisms will travel across the continent to the east coast without a change in period, and conversely 6.5-second microseisms originating on the east coast have been recorded at Sitka. However, from this study, there is no definite evidence that shorter microseisms cross over the Western mountain system, or that microseisms having any period less than 10 seconds travel far across the ocean bottom.

CONSTANTS OF THE SHORT-PERIOD SPRENGNETHER SEISMOGRAPH

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The reaction of the galvanometer on the pendulum is too large to permit the determination of the constants either by Galitzin's method, which neglects the reaction altogether, or by Rybner's method, which allows a small value of the reaction. The construction of the short-period Sprengnether does not permit the attainment of Galitzin's conditions: equal periods and critical damping. Even with the damping magnet removed, the pendulum is overdamped.

Following a method outlined by Coulomb and Grenet, the constants are determined for the usual operating set-up of this instrument.

Modifications to permit a better registration of local earthquakes are suggested.

MANTLE RAYLEIGH WAVES FROM THE KAMCHATKA EARTHQUAKE OF 4 NOVEMBER 1952

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Study of mantle Rayleigh waves from the Kamchatka earthquake of 4 November 1952 has resulted in additional dispersion data from R2, R4, R6, R7, R8, R9, R10, R11, R12, R13, R14, and R15. For periods under 400 seconds the group velocities are in excellent agreement with our previous observations. A few values of group velocity for periods 400–480 seconds have been obtained for the

first time and indicate that the dispersion curve begins to level off in this range. It is suggested that this is an effect of penetration to the core.

Calculation of the internal friction from absorption of waves with periods 250-350 seconds gives the value $1/Q = 370 \times 10^{-4}$. This is a little more than half the value deduced in an earlier study for periods 140–215 seconds.

RESULTS FROM TELESEISMIC RECORDS OF THE 1952 KERN COUNTY, CALIFORNIA, SHOCKS

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Some magnitude data and some travel times based on records at distant stations are discussed. The apparent velocity of direct longitudinal waves was between 8.1 and 8.2 km/sec at distances between 1½ and 4 degrees, but only about 7.8 km/sec between 4 and 12 degrees. At distances between 10 and 14 degrees there are at least seven stations at which the observed travel times are 3 to 5 seconds longer than given by the travel-time curves now in use. At a distance of about 12 degrees a higher apparent velocity of P-waves begins. All travel times at distances between 2 and 20 degrees can be explained on the assumption of a low-velocity channel at a depth of about 100–150 km. At distances between 20 and 35 degrees observed travel times are within ±2 seconds of the standard curves; at 35 to 70 degrees the observations are earlier up to an average of about 2 or 3 seconds near 60 degrees. For the remainder of the travel-time curve of P the average residuals are within ±1 second.

SOME GENERAL FEATURES OF LOW-VELOCITY LAYERS

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Some possible forms of the travel-time curve for longitudinal waves are discussed for the case in which there is a velocity minimum at a depth of about 100 km. On the other hand, if an earthquake originates in a low-velocity layer, waves leaving the source downward cannot enter the layers immediately below the surface unless they have reached a layer below the source with a wave velocity at least equal to the maximum velocity above the source. If an earthquake occurs in the strongly suspected low-velocity layer at a depth of about 15 km, waves starting downward must consequently reach at least the depth with a velocity of nearly 7 km/sec (which is the maximum above 15 km). The travel-time curve of these waves may easily be misinterpreted as caused by waves refracted at a discontinuity with a velocity of 7 km/sec below it. A large fraction of the energy enters the low-velocity channel.

OPERATIONAL CHARACTERISTICS OF THE BENIOFF VARIABLE RELUCTANCE SEISMOMETER

J. H. Hamilton

Benioff seismometers have been in general use for about 20 years. During this time several papers have been published on the characteristics of the instruments as determined by theoretical analysis and weight-lifting tests. To the author's knowledge this is the first time that the characteristics of the instruments have been explored by shaking-table tests.

The shaking-table tests include the determination of seismometer damping by the ratio of response method, the undamped and damped transducer terminal voltage as a function of frequency, and the overall frequency response and phase shift for various degrees of seismometer-galvanometer coupling. These tests indicated a discrepancy between the response determined by the shaking table and the response as predicted by S. K. Chakrabarty (1949). It is believed that the discrepancy can be explained if the inductance of the coils and the mutual coupling between coils is included in the theory. Until the theoretical analysis of the instruments can be extended to account for this dis-

crepancy, an empirical method for determining magnification based on a comparison between shaking-table and weight-lifting tests has been developed which gives good results when damping is properly determined.

The shaking table used in these tests employs a hydraulic system for driving the table. The table has an amplitude range from 0 to 10 microns peak-to-peak and a frequency range from 0 to 100 cycles per second.

IMPULSIVE FLUID PRESSURES ON WALLS OF CONTAINERS

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When the walls of fluid containers are subjected to acceleration, as during strong earthquakes, dynamic pressures of an impulsive type and of a convective type are generated. This paper presents simplified formulas for the impulsive fluid pressures on walls of various shapes, vertical and inclined, rectangular, trapezoidal, and cylindrical.

SEISMOLOGICAL INVESTIGATIONS IN BRITISH COLUMBIA

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During 1951 two seismograph stations, one at Horseshoe Bay and one at Alberni, were added to the existing station at Victoria, B. C. During the 1½ years the stations have been operating, approximately 75 earthquakes have been located by the network of stations. These seem to show a trend toward active and inactive areas, with that part near southern Vancouver Island being most active.

CRUSTAL STRUCTURE AND SURFACE-WAVE DISPERSION. PART IV: ATLANTIC AND PACIFIC OCEAN BASINS

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Properties of the ocean-ocean floor acoustical system pertinent to the study of microseisms are deduced from earthquake surface waves. First mode Love and Rayleigh waves on seismograms from the Honolulu station indicate that no submerged land masses of continental proportions underlie the Pacific Ocean as outlined by the earthquake belt. Similar results are obtained for parts of the Atlantic. The method, however, is insensitive to relatively small or thin structures. The Easter Island Rise is anomalous and possibly includes a thin layer of continental-like material.

Some earthquakes generate a short-period train of surface waves over oceanic paths. The beginning is identified as Love wave motion. The later part of the train, which is not definitely identified, is very similar to long-period microseisms. These waves are sharply attenuated at continental margins but propagate easily through either continents or oceans. The sources show distinct geographical preferences.

KERN COUNTY AFTERSHOCKS: PROGRESS REPORT

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Aftershocks of the major earthquake on July 21 are being investigated from seismograms for 15 continuously recording stations and 12 temporary locations, plus additional records lent by the University of California and the U. S. Coast and Geodetic Survey. Shocks of magnitude 5 and over all have been studied, and shocks of magnitude 4–5 in part.

Epicenters are grouped as follows: (A) southeast of the White Wolf fault, at distances chiefly about 5–10 miles; (B) north of Caliente; (C) east of Caliente, nearly in line with the fault; (D) near the fault on the northwest; (E) aligned NE–SW a few miles east of Bakersfield. All within the first

36 hours are of the group A (but results for the first 7 hours are fragmentary). Group B began with a shock of magnitude 6 after 36 hours; Group D on July 25, with many aftersocks; Group E on July 29.

The work has assumed V = 6.34 km/sec for direct waves and 8.2 km/sec for Pn. Results indicate systematic early arrival at the shortest distances. Depths vary; many shocks fit the standard assumption of h = 16 km, but others, especially Group C, appear shallower, and some are deeper.

First displacements at all near stations were toward the epicenter when recording the main shock (consistent with reverse faulting), but most of the large aftershocks show azimuth distribution of compressions and dilatations, probably calling for at least partial strike-slip.

The effect of the "root" of the Sierra Nevada is confirmed.

TRAVEL TIMES OF REFLECTED PHASES IN SOUTHERN CALIFORNIA EARTHQUAKES

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Travel-time curves for reflected waves from crustal discontinuities have been constructed, using records of near-by earthquakes in several parts of Southern California. Focal depths and depths to reflecting horizons have been computed using velocity functions obtained both from earthquake data and from timed blasts.

Results for three parts of Southern California are presented.

SOUTHEASTERN SECTION (GSA)

ZONING OF MIDDLE AND UPPER ORDOVICIAN ROCKS OF NORTHWEST GEORGIA BY LITHOLOGY AND PALEONTOLOGY

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Ordovician formations occur in seven strike belts extending northeast-southwest across the western half of the Paleozoic Province in Northwest Georgia. Heretofore, correlation from one belt to another has been difficult.

The middle and upper Ordovician limestones are divided into 26 distinct zones (on the basis of lithology and paleontology) which are given sequential numbers from bottom to top without regard to pre-existing formation names and are mapped in relation to the bentonite beds which are used as key horizons. Although the total thickness ranges from 1300 to 1900 feet, the individual zones can be traced from one strike belt to another and hence should be of value in correlation and in overcoming the confusion which now exists.

MINERALOGY OF THE CHATTANOOGA SHALE

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Mineralogical studies, both qualitative and quantitative, of the Chattanooga shale are in progress. Problems of separation and analysis of mineral and organic components are difficult because the rock is fine-grained. However, the application of light and electron microscopy, x-ray diffraction, differential-thermal analysis, and other methods has provided data of interest.

In thin section the rock is seen to consist of grains of quartz and feldspar in a matrix of yellow to red-brown organic material which incorporates shreds of mica and probably clay particles and is dotted by small clusters of pyrite. Larger organic fragments with associated pyrite are common and take various forms. Individual mineral particles range from pyrite cubes less than 0.15 micron on a side to quartz and feldspar grains as large as 0.25 millimeter. Certain heavy minerals are characteristic of the sediment, and x-ray study shows several types of clay minerals present.

Investigations of the radioactivity involve the use of counting, fluorimetric, and autoradiographic techniques. The latter have been particularly fruitful in attempts to discover the nature and occurrence of the uranium in the rock.

Quantitative studies of the minerals are being made by a combination of chemical and mineralogical methods.

SHALLOW-WATER ORIGIN OF THE CHATTANOOGA SHALE

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The Chattanooga shale, predominantly Devonian, is composed chiefly of silt- and clay-size quartz, clay, mica, pyrite, and considerable organic matter. Phosphatic grains and fossils are also common. The clastic grains are well sorted into paper-thin laminations. The shale lies on a smooth and extensive peneplain that bevels many gently dipping formations.

Seven circumstances do not fit a deep-water hypothesis, but indicate a shallow-water origin: (1) The black shale, or its thin basal sandstone, lies directly on the underlying unconformity. (2) Commonly the only coarse detritus at the base is a fraction of an inch of fine- to medium-grained sandstone. (3) The perfection of lamination, the high degree of sorting, and evidence of widespread migration of the sediments suggest frequent agitation. (4) Because of slow inundation, different parts of the shale are in contact with the underlying rocks. (5) Most of the area has not been deeply inundated at any other time since the Precambrian. (6) Elsewhere similar shale is interbedded with shallow-water sediments. (7) The sea spread suddenly at the end of the deposition of the Chattanooga and

presumably, therefore, was somewhat deeper; yet it is generally agreed that the Mississippian beds, which lie conformably above the shale, accumulated in a shallow sea.

Black muds are accumulating today in shallow waters of the Norwegian fjords and the Baltic Sea. Attempts to prove that the muds of the Chattanooga accumulated in deep water seem to require highly improbable conditions.

SUB-CHATTANOOGA RESIDUUM IN TENNESSEE AND KENTUCKY

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Between the black Chattanooga shale in Tennessee and Kentucky and the underlying limestone altered to dolomite in places is a clayey buff-colored zone up to several feet thick. This zone represents an acid-leached zone of the limestone, the acid (sulfuric) being derived from oxidation of the abundant pyrite present in the black shale; it is not, as has been suggested, a paleosol, of pre-Chattanooga age. The intensity of the alteration of the limestone decreases with distance from the base of the black shale; several stages of alteration are recognized and described. With the alteration of the limestone, the shale is attacked more or less, as indicated by locally conspicuous efflorescences of copiapite, coquimbite, halotrichite, gypsum, and probably other sulfates. Among the secondary minerals in the clayey residuum, basaluminite (a hydrous aluminum sulfate) was found in geodal cavities; this mineral has been previously found only in England and France.

The petrography and chemical composition of the leached zone are described and illustrated.

A brief discussion of criteria of identification of ancient soils (paleosols) is given, but no evidence of any ancient soils is found here.

KYANITE QUARTZITE DEPOSITS OF THE SOUTHEASTERN STATES*

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Kyanite-bearing rocks occur at many places in the metamorphic belt of the Southeastern States. Kyanite quartzite has been the major source of the kyanite mined in the region; reserves of this material are very large. Kyanite schist and gneiss, and kyanite-bearing quartz veins and pegmatites also are common. Most of the kyanite quartzite deposits are in two principal areas. One of these areas, in Virginia, includes the deposits at Baker, Willis, and Woods mountains; a second, in the Carolinas, includes the deposits at Clubb and Kings mountains in North Carolina, and at Henry Knob in South Carolina. Other large kyanite quartzite deposits are at Hagers Mountain, North Carolina, and at Graves Mountain, Georgia.

The dominant mineral constituents in most of these deposits are kyanite qnd quartz, although at a few places the Al_2SiO_5 mineral is sillimanite or andalusite. The minerals most commonly associated with quartz and the Al_2SiO_5 minerals are muscovite, rutile, and pyrite; significant accessory minerals in some deposits are pyrophyllite, topaz, clay minerals, paragonite, chloritoid, and lazulite.

Detailed geologic mapping indicates that the kyanite quartzite bodies in the two principal areas originally were sedimentary beds that have been folded and metamorphosed; they are now associated with several types of mica schists and hornblende gneisses. In the Kings Mountain area, some quartzite bodies near granite contain sillimanite rather than kyanite. The alumina in the kyanite (or sillimanite) quartzite bodies of these two areas presumably was present before regional metamorphism and is probably of sedimentary origin; however, there has been some migration of alumina during metamorphism. On the other hand, in some of the other kyanite quartzite deposits in the southeast, the alumina may have been introduced either before or during metamorphism.

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* Publication authorized by the Director, U. S. Geological Survey

COMMENTS ON THE GEOLOGY OF THE ELLIJAY QUADRANGLE, GEORGIA-NORTH CAROLINA-TENNESSEE

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The geology of this 30-minute quadrangle base for the Ellijay folio (Geology by Lawrence LaForge, 1912) will be reviewed briefly, detailed work planned for the area by the Georgia Geological Survey will be mentioned, and some past and present interpretations of the geology will be discussed.

Northwest of the Murphy series, underlying rocks (Great Smoky formation) are here classified into several generalized depositional units, two of which occur in this quadrangle west of the Murphy series, and reoccur east of the Murphy series where they are overlain by granulites and biotite quartzites which form the central part of the Blue Ridge synclinorium, extending into the southeastern part of the Ellijay quadrangle.

PRELIMINARY INVESTIGATION OF THE RELATION OF THE GRANITES TO REGIONAL METAMORPHISM IN HART COUNTY, GEORGIA

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Evidence for the relationship is derived from three partially independent sources: (1) the deformational character of the granite as compared to the country rock; (2) the textural conditions in the contact zones showing that the country rock must have been at approximately the same temperature as the granite at the time of its formation; (3) mineralogical criteria, which indicate that the P, T conditions in the granites are those of the epidote amphibolite facies, while the P, T conditions of the country rock are those of the amphibolite facies.

It is concluded that the granites were intruded after maximum metamorphism.

BORDER ROCKS OF THE IDAHO BATHOLITH NEAR RIGGINS, IDAHO

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The northern part of the 30-minute Riggins quadrangle in west-central Idaho contains about 35,000 feet of eugeosynclinal metavolcanic and metasedimentary rocks of Permian, Triassic, and Jurassic (?) ages. From phyllites and greenstones on the west, the rocks increase in metamorphic rank through schists and amphibolites to a complex of paragneisses, migmatites, and gneissose and massive granitic rocks, which forms the border zone of the Idaho batholith.

Tabular bodies of granitic gneisses ranging from an inch to a mile in thickness are conformable with complex structures of the metamorphic rocks in the border zone. Gneissic quartz diorite with abundant layers of metamorphic rocks grades into paragneiss with abundant granitic intercalations by changing proportions of intercalated granitic and metamorphic rocks. These granitic gneisses are thought to have resulted, like the metamorphic rocks with which they are intercalated, from regional and plutonic metamorphism of volcanic and sedimentary rocks. Some of the migmatites are believed to have resulted from differential fusion of metamorphic rocks and to have had sufficient mobility to intrude upward.

The rocks described above are intruded by several sharply bounded discordant plutons of quartz monzonite and granodiorite.

The border rocks of the Idaho batholith near Riggins are much like the rocks of the Shuswap terrane, British Columbia. The rocks are unlike those of some other parts of the Idaho batholith and those of the Sierra Nevada batholith of California, where there is little development of gneisses and migmatites.

AGE OF THE CHATTANOOGA SHALE AND THE MAURY FORMATION

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The Chattanooga shale of central Tennessee and adjoining States is here considered Late Devonian, though the oldest beds of the formation may be late Middle Devonian. The most nearly complete sections are best exposed along the Eastern Highland Rim of Tennessee from southern Jackson County south to Bedford and Coffee counties.

The Maury formation is considered early Carboniferous (Kinderhook) except in a part of north-central Tennessee where the basal bed is classified as very late Devonian.

The age designation, faunal zonation, and correlation of the Chattanooga shale and the Maury formation are based on a study of conodonts in 325 collections from 65 measured sections.

GEOCHEMISTRY OF METAMORPHISM

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Metamorphism is a chemical, mineralogical, and structural adjustment of solid rocks to new physical and chemical conditions. The geochemistry of metamorphism deals with the changes in the chemical composition of the rocks during the metamorphism. Two processes, metasomatism and metamorphic differentiation, are concerned. Both processes involve a considerable migration of matter and may proceed simultaneously. The agent of metasomatism may be either an igneous magma or solutions derived from ultra-metamorphic rocks. Both are supported by field evidence. A general relationship is found between the emplacement of granites, either igneous or metasomatic, and the metasomatized country rocks. There is a strong suggestion that granitic composition would represent a state of chemical equilibrium in the upper lithosphere. Thus the general tendency of all migrations of elements would be toward the formation of granitic rocks. Many of the other products of metasomatism would result from a fixation of those substances which are expelled from the granitized areas.

Three principal modes of transfer of substances are considered:

(1) Elements are carried by liquids and gases that are pressed through the openings in the rocks.

(2) (a) Ions move by diffusion in a more or less stationary pore liquid. (b) Ions move along the grain boundaries.

(3) Ions move by diffusion through solid crystals.

LATERAL VARIATIONS IN THE AMOUNT OF SANDSTONE IN THE CHESTER SERIES OF WESTERN KENTUCKY, AND ITS RELATION TO THE OCCURRENCE OF OIL

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Well records show that both the proportion and the aggregate thickness of sandstone in the Chester series of western Kentucky decrease from west to east. The greatest total thickness of sandstone is approximately 400 feet in western Union and Henderson counties, and there is essentially none in several areas on the eastern and southeastern flank of the basin.

Local variations from the regional pattern are correlated with major structural features; in general, structurally high areas have anomalously large amounts of sandstone for their regional position, and structurally low areas have small amounts. The close association of sandstone content and local structure is attributed to the preferential accumulation of sand on submarine topographic highs created by "growing" structures and maintained by differential compaction.

The occurrence of oil in the Chester sandstones shows little relationship to the total thickness of sandstone, but is closely associated with local areas of anomalously large amounts of sandstone. Possibly the relatively more intense and prolonged current action to which the bottom "highs" were subjected led to the formation of a sandstone which could preferentially store oil. It is suggested that this sediment (the specific reservoir) was the determining factor in the localization of oil.

STRATIGRAPHY OF THE CHATTANOOGA SHALE

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Geologists of the University of Tennessee are studying the Chattanooga shale of the northern part of the Eastern Highland Rim, Tennessee. The formation ranges from 16 to 38 feet in thickness, except in the Flynn Creek "cryptovolcanic" area where it is up to 180 feet. Normally the Chattanooga disconformably overlies Ordovician formations and at the top grades into the Maury shale.

The section exposed along State Highway No. 26, immediately east of the Sligo Bridge across Caney Fork River (Center Hill Reservoir), DeKalb County, selected as typical of the area, follows:

	Feet
Maury shale. Green-gray shale	1.6
Chattanooga shale.	
Unit E. Shale, gray-black, massive, fissile. Prominent zone of phosphate nodules at top	7.25
Unit D. Shale, gray-black, silty, alternating with gray shale. "Varved" sandstone near middle	4.65
Unit C. Shale, gray-black, massive, fissile. Prominent overhang at base	5.40
Unit B. Shale, gray-black, fissile, alternating with gray shale. Bentonite (0.1 foot) near top	9.50
Unit A. Shale, gray-black, massive, fissile. Sand grains at base	6.00
Total Chattanooga	32.80
Ordovician (Leipers).	

Northwestward from Sligo the Chattanooga thins to 16 feet in the area immediately northwest of Gainesboro, Jackson County. The upper three units remain constant in thickness. Most of the thinning is in the lower two units. The bentonite has been traced northward to the Flynn Creek area, Jackson County, and is always less than 2 feet below the base of unit C.

BIOFACIES AND FAULTING, JACKSON COUNTY, FLORIDA*

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A normal fault striking northeast and located near Cypress, Florida, was discovered during a recently completed study of the geology of Jackson County, Florida. Isopachous and structural data indicate that this fault is of post-Oligocene, pre-Miocene age.

The data suggest that the fault zone acted as a structural axis during Cenozoic time. Biofacies of Ocala (upper Eocene) age indicate that deeper water existed on the downthrown side of the fault than on the upthrown side.

Warping of the downthrown block has produced a nose which closes against the fault.

Other data from the literature suggest that the upthrown block was structurally positive at least as early as the beginning of the Cenozoic.

MODE OF OCCURRENCE OF IRON ALONG THE MISSISSIPPIAN-CRETACEOUS CONTACT IN WESTERN KENTUCKY

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Numerous concentrations of limonite iron occur along the Mississippian-Cretaceous contact in western Kentucky. These deposits are a northern extension of the iron-bearing zone found in northern Alabama and western Tennessee.

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* Published by permission of the Director, The Florida Geological Survey, Tallahassee, Florida.

Opinions have varied greatly regarding the source of the iron, time of deposition, and means of concentration of the ores. The western Kentucky deposits were not included in the earlier studies. Field relationships and microscopic examinations of samples indicate a post-Tuscaloosa age for the ores. The iron has been reworked by ground waters from a source above the basal Tuscaloosa. Variations in types of ore are controlled by the thickness and lithologic differences of the Tuscaloosa, the depth of weathered material at the top of the Mississippian limestone, and the amount of secondary chert within the upper Mississippian beds.

STRUCTURE WITHIN TUCKALEECHEE COVE WINDOW, EASTERN TENNESSEE

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Tuckaleechee Cove, a large, irregularly shaped valley at the foot of the Great Smoky Mountains, is the largest of five windows through the Great Smoky overthrust fault. The overthrust describes a low arch of smooth contour around the cove. The overriding rocks are phyllite, sandstone, conglomerate, and limestone of the Ocoee series (late Precambrian ?). *Scolithus*-bearing quartzite of the Chilhowee group (Early Cambrian) forms one small klippe in the window.

Lower Ordovician limestone, folded and broken by many faults, forms an anticlinal core within the window. Middle Ordovician limestone, calcareous sandstone, and calcareous shale overlie the Lower Ordovician limestone, in normal stratigraphic succession in some places but with fault contact in others. In a few places limestone of the core has been carried over Middle Ordovician shale on minor thrust faults. Fault slices of Lower Ordovician limestone rest on Middle Ordovician shale and form the footwall of the overthrust under most of its trace around the window. Fossils contained in one of these slices are somewhat older than those in the limestone of the core.

The common presence of a fault contact between more competent Lower Ordovician limestone and less competent Middle Ordovician shale suggests a zone of subsidiary movement beneath the Great Smoky overthrust, concentrated at the boundary between these two series. Moreover, the fact that this fault zone truncates minor folds and faults of the core indicates two generations of movement, of which the Great Smoky fault and related structures are the younger.

GEOLOGY OF HAMME TUNGSTEN DISTRICT, VANCE COUNTY, NORTH CAROLINA*

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Geologic mapping, not yet completed, has been carried on in the Hamme Tungsten district, Vance County, North Carolina, by the U. S. Geological Survey in co-operation with the North Carolina Department of Conservation and Development during the period 1949–1952. Most of the area is underlain by a northeastward-trending lenticular mass of biotite-albite granite having a maximum width of about 7 miles and a length of at least 23 miles. East of the granite is a long, narrow strip of sericite-chlorite phyllites grading eastward into several gneisses. West of the granite are sericite-chlorite phyllites, greenstone, massive metafelsites, and metaquartzite. Small intrusives are composed of aplite, microcline granite, quartz monzonite, and hornblende diorite (or gabbro). Triassic(?) diabase forms many dikes and sills. Many quartz veins and lenses of several types fill fractures or foliation planesin all rocks of the area except diabase (and possibly diorite). Tungsten-bearing quartz veins, in both granite and phyllites, are confined to a narrow belt some 8 miles long near the western border of the granite. Foliation in most places parallels bedding but locally lies at a marked angle. The strike of foliated rocks is uniformly northeast; dips are steep and usually northwest. Field observations, not yet confirmed by petrographic study, suggest that the granite may have been formed by metamorphic rather than igneous processes.

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* Publication authorized by the Director, U. S. Geological Survey.

PRELIMINARY SURVEY OF SEDIMENTS OF PARTS OF MISSISSIPPI SOUND

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During the summer of 1952 a preliminary survey was undertaken to study inshore bottoms of parts of Mississippi Sound, in order to determine the physical and chemical nature of bottom materials with reference to data on the distribution, mortality, and abundance of oyster, shrimp, and fish. Eventually it is hoped to find the types of bottom most favorable for various species, especially for oysters, so that new beds can be propagated.

Cores were taken from the biologically important upper 15 inches of sediment and then rushed to the Gulf Coast Research Laboratory, Ocean Springs, Mississippi, for examination by marine biologists. A portion for sedimentary analysis was then elutriated in sea water, and each elutriated fraction examined microscopically while wet. Rough quantitative chemical analyses were made of the silica, alumina, and organic carbon content, but more detailed analyses are planned.

Microscopic examination showed considerable diversity in grain size although 90 per cent of most samples fell within a narrow size range. Oyster bottom is fine sand to coarse silt, whereas shrimp bottom is fine silt to clay in grain size. Approximately 95 per cent of the grains is quartz, 4 per cent is chert, and the remainder is muscovite, garnet, biotite, epidote, feldspar, apatite, magnetite, and zircon. Differences in rounding, frosting, and freshness are apparent, but the striking feature is fresh-appearing, rather large muscovite cleavages in oyster bottom, which may provide the firmness of bottom necessary to support growing oysters.

PALEOGEOGRAPHIC IMPLICATIONS OF EVIDENCES POINTING TO FONDO ORIGIN OF THE CHATTANOOGA-NEW ALBANY-OHIO BITUMINOUS SHALES

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That the Chattanooga-New Albany-Ohic bituminous shales were deposited in a fondo environment—*i.e.*, in quiet, unaerated, toxic water below wave base—is indicated by the fine material, bedding, general absence of cross- or current-bedding, fine laminations to the very bottom, high content of light-weight organic constituents, and the wide distribution of very thin beds of bentonite and half-inch siliceous beds believed to be altered very fine ash.

These shales rest with regional disconformity on beds ranging from Ordovician to Middle Devonian, almost invariably with a smooth, clean-cut contact against fresh rock.

Almost everywhere, a basal sandy unit, generally 0.1 inch to 3 inches thick, underlies the bituminous shale. Characteristically this is an unstratified mixture of rounded and frosted quartz sand, fish teeth and plates, bone, conodonts, and abundant phosphate nodules. This material has all the characteristics of a lag concentrate accumulated on the sea floor when current action was strong enough to prevent deposition of fine material but too weak to move the coarser debris.

Phosphate nodules, bone fragments, and small pebbles pressed into the underlying limestones suggest they were not yet consolidated when the lag concentrate was deposited.

On the borders of the Cincinnati arch, especially on the east, the lag concentrates appear at the base of the bituminous shales and also in zones of the Devonian limestones and in dolomites, possibly of Silurian age. In the same areas the Devonian and Silurian limestones and dolomites wedge out toward the arch. In north-central Kentucky dolomite interfingers with the bituminous shales above the lag concentrate.

The major problem is how to reconstruct the paleogeographic environment so as to harmonize with the facts. Only the broad regional disconformity seems to fit the concept of a sea advancing over a land surface.

The following is suggested:

(1) Gradual *relative* uplift of the Cincinnati-Nashville arch and the Ozark dome during the Silurian and Early and Middle Devonian, with probable subaqueous wave planation on all the higher parts

of the arch and, for the Ozark dome, possible emergence during an erosional interval between the Silurian and the Devonian.

(2) Thinning of Silurian and Devonian depositional units toward the arches.

(3) Long periods of nondeposition, with the formation of lag concentrates during various intervals, especially in the Devonian,—these increasing with nearness to the arches.

(4) A long period of nondeposition with formation of the basal lag concentrate over a wide area immediately preceding the deposition of the bituminous shales. Tidal currents in an unobstructed seaway presumably prevented deposition of the finer materials.

(5) Rise of a barrier, decreasing or stopping current action and initiating toxic water conditions during the deposition of the bituminous shales.

(6) Continued relatively high stand, but not emergence, of the central parts of the arches and domes during the earlier part of the period of black shale deposition, so that the high areas were kept free from sediment for a time while bituminous shale and, locally, gray nonbituminous shale were being deposited around them.

(7) Final deepening of the water so that bituminous shale was deposited everywhere except possibly on the highest parts of the arches.

"ST. LOUIS" LIMESTONE (MISSISSIPPIAN) OF THE SOUTHERN APPALACHIANS

John E. Sanders
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Strata referred to as correlative with the St. Louis limestone (mid-Mississippian) have been recognized in northeast Tennessee and elsewhere in the Southern Appalachians since Safford's (1869) discussion of the "*Lithostrotion* bed." Butts (1926; 1940) identified the "St. Louis" limestone both in Alabama and Virginia. Reger (1926) proposed the name Hillsdale limestone for beds in West Virginia similar to Butts's "St. Louis", and Hillsdale has since been adopted by B. N. Cooper (1944; 1948) and Wells (1950), because use of "St. Louis" in the Appalachians implies a correlation based on inadequate evidence.

Detailed mapping of Mississippian limestones in the Greendale syncline in Hawkins County, Tennessee, by the writer for the Tennessee Division of Geology has led to discovery of three mappable units within Butts's "St. Louis" (Hillsdale of recent workers), as used in southwestern Virginia: a basal cherty black limestone, 80 feet thick, with intercalated siltstone; a middle siltstone unit, approximately 120 feet thick; and an upper massive black limestone unit, 130 feet thick. Both lower and upper limestone units contain the "guide fossils" to Butts's "St. Louis" limestone, but the middle siltstone unit contains a fauna similar to that from the middle member of the Grainger formation (Sanders, 1952).

The writer has recognized this threefold division of Butts's "St. Louis" limestone as far northeast as Saltville, Smyth County, Virginia. Inadequate exposures and lack of understanding of the peculiar faunal relationships of these three subdivisions in southwestern Virginia caused Butts (1940) to identify certain "St. Louis" beds at Saltville as "Warsaw" and to mislabel certain fossil collections made therefrom.

RELATION OF MINERAL DEPOSITS TO METAMORPHIC ROCKS

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The crystalline rocks of the Southeastern United States contain deposits of practically every mineral considered characteristic of metamorphic rocks. Asbestos of anthophyllite and amphibole varieties is found as irregular deposits in highly metamorphosed peridotite and pyroxenite. Graphite forms

bands and lenses in mica schist. Garnet occurs in varying amounts in rocks varying from hornblende gneiss to mica schist. Talc forms lenses and irregular bodies in dolomitic marble, while talc and soapstone are found in a wide variety of highly metamorphosed ultrabasic igneous rocks. Pyrophyllite occurs as irregular lenses in metamorphosed acid volcanic fragmental and flow rocks. Both kyanite and sillimanite occur as irregular deposits in mica gneiss and mica schist. Some of these deposits have only scientific value, but many are of economic importance.

ABSTRACTS OF PAPERS SUBMITTED TO THE MEETING IN BUTTE, MONTANA MAY 8, 1953

ROCKY MOUNTAIN SECTION (GSA)

LOUIS BERYL PEGMATITE, BLACK HILLS, SOUTH DAKOTA

Walter C. Ackerman
South Dakota School of Mines, Rapid City, S. D.

The Louis beryl pegmatite is located in the Southern Black Hills, 25 miles northwest of Pringle, South Dakota, in the vicinity of the Harney Peak batholith. Mapping shows that the pegmatite is concordant with the schistosity planes of the schist which trends N. 30° W. and dips vertically.

The pegmatite is rudely zoned. Petrologic studies show that the core, which is quartz and microcline, grades into a perthitic microcline zone. Surrounding this perthitic microcline zone is a perthite zone, grading outward into an albite-oligoclase border zone. No zone has sharp contacts, and graphic texture is prevalent except in the core.

The quartz-mica schist surrounding the pegmatite is highly altered and feldspathized. Chemical analysis of the schist indicates that the pegmatite could have been derived by reworking of the schist. The range of oxides of the schist falls within the range of granites and granite pegmatites.

The mechanics of preferred orientation of crystals by differential thermal conductivity are stressed.

URANIUM IN THE GOLDEN GATE CANYON AND RALSTON CREEK AREAS, JEFFERSON COUNTY, COLORADO

John W. Adams
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Pitchblende associated with base-metal sulfides has been found at eight localities in the northern part of Jefferson County, Colorado, in shear zones that cut Precambrian metamorphic and igneous rocks, chiefly hornblende gneiss, biotite schist, and granite pegmatite. The known deposits are in the vicinity of Golden Gate Canyon and Ralston Creek in the foothills of the Colorado Front Range and about 15 miles east of the pitchblende-producing area of the Central City district.

With one exception, the pitchblende deposits are in major shear zones that contain veinlike bodies of carbonate-rich breccia. The breccia bodies range from 1 to 6 feet in thickness and probably originated during Laramide orogeny. The breccias in the vicinity of the deposits are composed of fragments of bleached and iron-stained wall rock, usually hornblende gneiss, that have been veined and cemented by carbonate minerals, quartz, and orthoclase?. Pitchblende and associated ore minerals, chiefly copper sulfides, occur in and along the margins of the breccias. The size of the ore bodies is not yet known, but a 4-foot width of ore containing 0.81 per cent uranium has been found in one deposit. The uranium and copper minerals apparently were introduced at a late stage of the carbonate deposition.

Secondary uranium minerals are subordinate except at the Schwartz mine, where torbenite is common. Some alteration of pitchblende to nonopaque materials, believed to be hydrated oxides, has been noted in ore from two deposits.

LATE CRETACEOUS-EARLY TERTIARY SEDIMENTS IN EASTERN MONTANA

Kirk Badgley, Jr.
Geology Department, University of Wyoming, Laramie, Wyo.

Shell Oil Company has measured a series of sections of late Cretaceous-early Tertiary sediments along a north-south line from Fort Peck Reservoir to the Yellowstone River. The sediments thicken southward, although the thickness of the Lebo shale remains relatively constant. A grain size, shape, and composition analysis is being made to correlate adjacent units and to learn if there is any correlation of heavy minerals with those in the same stratigraphic units as studied by Stowe in the northern Big Horn Basin.

URANIUM-VANADIUM DEPOSITS NEAR EDGEMONT, FALL RIVER COUNTY, SOUTH DAKOTA

W. E. Bales, Henry Bell, and V. R. Wilmarth
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Uranium and vanadium minerals were found near Edgemont, Fall River County, in the southern part of the Black Hills, South Dakota, in the Lakota and Fall River sandstones of the Inyan Kara group (Early Cretaceous). Uranium occurrences are known in the Deadwood formation and Minnelusa sandstone (Paleozoic) and have been reported from the Pierre shale (Late Cretaceous). Most high-grade deposits are in an area of approximately 20 square miles on the gently dipping southwest flank of the Black Hills uplift. Minor northward-trending anticlines lie east and west of the known mineralized area. These folds may be related to northward-trending shear zones of complex structure in the Precambrian rocks that crop out about 10 miles to the north.

The ore bodies apparently were localized by (1) thin bedding rather than massiveness of the sandstone beds, (2) local changes in dip, (3) minor faults, and (4) fracture zones.

The ore minerals are carnotite, tyuyamunite, rauvite (?), hewettite, metahewettite, autunite, and other unidentified uranium minerals. They form fracture fillings and disseminations through sandstones and shales, with a gangue of calcite, gypsum, and limonite.

Geologic guides useful in prospecting for uranium in the Edgemont area are (1) a brick-red staining of the sandstones near deposits of uranium and vanadium minerals, (2) abrupt, local changes of dip, (3) thin-bedded—rather than thick-bedded—sandstone, (4) abundant organic material in sedimentary rocks, and (5) proximity to northward-trending fracture zones.

URANIUM DEPOSITS IN THE NORTHERN PART OF THE BOULDER BATHOLITH

George E. Becraft
U. S. Geological Survey, Spokane, Wash.

Uranium minerals have been found in the northern part of the Boulder batholith in at least three mineralogical and structural environments. At the Gray Eagle and Comet mines the uranium minerals are spatially associated with minerals containing base and precious metals in a persistent shear zone. At the W. Wilson mine they are associated with chalcedonic quartz containing sparse pyrite and very small amounts of other sulfides. The Lone Eagle deposit has some characteristics of each of the foregoing types of deposits.

A map showing the distribution of anomalous radioactivity in the northern part of the batholith is presented with a discussion of the possible relations between uranium deposition and rock types.

PETROGRAPHIC FEATURES OF THE NORTHEASTERN PART OF THE BOULDER BATHOLITH

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Quartz monzonite of the Boulder batholith in the vicinity of Clancy Creek, Jefferson County, Montana, can be separated into four mappable units. The most common unit is an equigranular, medium-grained, biotite-hornblende quartz monzonite, the "normal" rock type of the batholith. The second quartz monzonite is seriate to distinctly porphyritic with partly replaced phenocrysts of quartz, plagioclase, and potash feldspar—in the same ratio as in the "normal" rock type—set in a micro-alaskitic groundmass. The third quartz monzonite is similar to the second one, but contains large euhedral phenocrysts of orthoclase up to 1.5 inches long. The fourth quartz monzonite is fine-grained, very light colored, and has more quartz than the others.

The last three quartz monzonites were formed apparently by partial to complete replacement of the "normal" quartz monzonite by solutions rich in potash and silica. These solutions were probably derived, at least in part, from the reservoir from which the later alaskitic rocks were formed.

DIAPIRITE METAMORPHISM OF GYPSUM, SEVIER COUNTY, UTAH

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Extensive lenses of commercial-grade gypsum are well exposed along the east margin of Sevier Valley, between Salina and Sigurd, Utah. The gypsum beds are typical members of Upper Jurassic

Arapien shale. The N. 35° E. trending belt of Arapien shale is predominantly blue-gray "paper" shale with interbedded siltstone, calcareous sandstone, masses of salt (halite), and lenses of gypsum that are exposed in northeast-trending folds, en echelon.

The gypsum-bearing shale is in one of the most significant orogenic zones of Utah, and the effects of diapirite metamorphism are described as resulting from stresses initiated during Laramide thrust faulting. Décollement of the mobile Arapien shale lying on competent Navajo sandstone is postulated, and dislocation of the massive lenses of gypsum is described in relation to diapiric movements of mobile halite and incompetent "paper" shale. The resulting extreme examples of disharmonic folds (piercement folds), zig-zag or V folds with consequent repetition of the section, are described.

Only minor gypsification of anhydrite is attributed to circulating ground water. The Sigurd-Salina gypsum occurs as primary central beds with less hydrous margins that contain anhydrite. The ratio of anhydrite to gypsum is a function of the structural complexity, and the least-deformed areas contain the most extensive deposits of pure gypsum. These observations are supported by diamond-drill data and by chemical and petrographic analyses, which are also used to demonstrate anhydritization of the gypsum.

RADIOACTIVITY LOGGING AND ITS APPLICATION IN PALEOZOIC CORRELATIONS

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A short explanation of the method and technique used in recording the Radioactivity log, and a brief explanation of how to interpret.

This will be followed by slides showing the different correlation features of the Paleozoic group. A long range correlation chart will also be shown on a slide, covering some 550 miles.

TYPES OF LOCAL SEDIMENTARY STRUCTURES IN SASKATCHEWAN

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The southern half of Saskatchewan is underlain by gently dipping sediments ranging in age from Cambrian to Paleocene, with all periods represented except the Pennsylvanian and the Permian. In general these sediments dip into the Williston Basin. Types of local structure encountered during the oil exploration program vary somewhat from those encountered in Alberta. These anomalies have been classified into four groups: (1) true tectonic uplifts involving all the sedimentary section; (2) anomalies involving Devonian and younger sediments which are believed to have been caused by leaching of the Devonian salt section and subsidence of overlying formations; (3) anomalies caused by buried Paleozoic topography, some of which do not affect the attitude of the overlying sediments, and others of which show draping over buried Paleozoic hills; and (4) structures involving the younger formations overlying undisturbed older sediments. Slides illustrating these anomalies will be presented.

CONTACT PHENOMENA IN THE VICINITY OF DIVIDE, MONTANA

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About 30 miles south of Butte, Montana, the Big Hole River cuts through the southern tip of the Boulder batholith revealing contact phenomena generally quite different from other parts of the batholith. As previously mapped, the outcrop pattern shows what appears to be a discordant intrusion cutting cleanly through the Laramide folds in Paleozoic and Mesozoic strata with a broad band of metamorphism. The granite is overlain by early Tertiary gravels. This dates the intrusive as probably early Eocene.

How did the intrusive mass acquire space for itself? A cursory study of the area furnishes a partial answer: (1) The intrusion is only partly discordant, (2) a fairly large portion of the granite is traceable to granitized host rock, and (3) the intrusive probably narrows in depth.

More careful mapping of the contact shows the intrusive to be more concordant than first indicated. The sedimentary rocks have been shattered and spread apart with sill-like penetrations of granite. On a somewhat smaller scale extreme brecciation is outstanding; stringers of granite penetrate the metamorphosed sedimentary rock, and abundant xenoliths are lodged in the granite.

Evidence that much of the granite has been derived from granitized or partially granitized host

rock comes from xenoliths, xenocrysts, and phosphatic contamination resulting from assimilation of the Phosphoria formation.

Finally, a narrowing of the granite outcrop where it is cut by the canyon and the fact that the granite has intruded a synclinal area suggests a funnel-shaped or lopolithic structure.

GRANODIORITE INTRUSION, AMISK LAKE-FLIN FLON REGION, NORTHERN SASKATCHEWAN*

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The Amisk Lake-Flin Flon region lies just west of the Saskatchewan-Manitoba boundary between latitudes 59°30′ and 55°00′.

The stratigraphic sequence consists of a volcanic-sedimentary assemblage referred to as the Amisk group which is overlain unconformably by a sedimentary series known as the Missi. A third group, the Kisseynew gneisses, lies to the north and is believed to be the metamorphosed equivalent of the Amisk and Missi. All three groups are Precambrian. The granodiorite intrudes strata of all three assemblages.

The larger masses of granodiorite are elongated parallel to the regional structures. Some are regarded as huge sill-like masses and laccoliths, others as conformable batholiths or large phacoliths.

Textural variation from primary granitoid and porphyritic to secondary granoblastic, attitude of lineation and foliation and their relationship to the structures of the enclosing rocks, the nature and attitude of inclusions, and the structural features of related pegmatite sills and dikes indicate that the intrusions are syntectonic.

Rotation of inclusions, definite intrusive relationships along most contacts, and satellitic dikes showing dilation of the walls are evidence that the material which formed these bodies of granodiorite was emplaced mainly as a liquid or magma.

PROBLEMS IN THE PETROLOGY OF THE BOULDER BATHOLITH, MONTANA

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The Boulder batholith, of Eocene age, is a pluton of quartz monzonite with associated volcanic rocks that underlies an area of 1200 square miles in western Montana. The writer has undertaken a comprehensive study of the petrology of this body. This project is part of a detailed study of the batholith by the United States Geological Survey.

No significant conclusions have yet been reached, but the work has progressed far enough to reveal eight outstanding problems: (1) What are the distribution, mineralogy, and chemical composition of the various rock types, and how are these types related to one another? (2) What structural features do the plutonic rocks possess, and what do these features reveal about the mode of emplacement? (3) How is the Boulder batholith related to the Idaho batholith? (4) What was the mineralogical and chemical evolution of the magma that gave rise to the various rock types? (5) Where and in what manner does uranium occur in the batholith? (6) Are the aplites and alaskites significantly related to the ore deposits? (7) What is the relationship between rock alteration and ore deposition? (8) What are the contact-metamorphic effects of the pluton on the surrounding sedimentary and volcanic rocks?

Recognition of these clear-cut problems should help to guide the petrologic study toward a better understanding of the nature and genesis of the Boulder batholith.

CREVASSE FILLINGS ON THE GLACIATED PLAINS OF NORTHEASTERN MONTANA

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Crevasse fillings occur in two large areas in northeastern Montana. One area, about 15 miles wide, extends southeastward for about 30 miles from Turner in Blaine County to Freewater in Phillips

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County. The other area, 6 to 20 miles wide, extends southwestward for about 100 miles from a point 10 miles southwest of Westby in Sheridan County to a point 10 miles west of Frazer in Valley County.

The crevasse fillings are essentially straight ridges of till as much as 20 feet high, 100 to 200 feet wide, and as much as 2 miles long. Some of the ridges intersect at well-defined angles ranging from 30° to 90°; this differentiates the crevasse fillings from recessional moraines, which do not intersect.

The overall pattern is thought to represent fractures in stagnating ice. The long ridges are interpreted to be normal to the direction of ice movement, which was mainly southeast in the Blaine-Phillips County area and mainly southwest and west in the Sheridan-Roosevelt-Valley County area. Two separate gradually stagnating ice lobes are believed to have existed in these two areas. The absence of water-sorted material in the ridges is thought to indicate that ice wastage was very slow, principally by evaporation or sublimation.

PINE VALLEY LACCOLITH, WASHINGTON COUNTY, UTAH

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The Pine Valley Mountains in southwest Utah are largely made up of a floored intrusion, now deroofed. The greatest remaining thickness of the body is 3000 feet, and the exposed extent is 70 square miles. The base, which is exposed or thinly covered by talus for about 25 miles, rests concordantly upon the Eocene Claron formation. The laccolith lies in a broad shallow syncline and, laterally, is in intrusive fault contact with Tertiary volcanic rocks.

Megascopically, the rock is an andesite porphyry; microscopically, it is closer to a latite or monzonite porphyry. Phenocrysts of calcic andesine with considerable augite and some biotite constitute about half the rock; the much finer-grained groundmass consists mainly of orthoclase. Unlike the phenocrysts, which do not vary much in size throughout the laccolith, the groundmass is coarser-grained toward the interior of the body.

Deuteric alteration effects are extensive, but are best developed in a zone about 1300 feet above the base of the intrusion; here the rock, bleached by destruction of its mafics, has a miarolitic porosity as high as 9 per cent. Throughout the body much secondary magnetite has been produced at the expense of augite and biotite. Gravitative settling during cooling apparently was unimportant.

The volcanism which preceded emplacement of the laccolith culminated in extrusion of a rock similar to that which composes the laccolith. Under the cover of these volcanics, the intrusion moved in as a semiliquid mass heavily charged with intratelluric crystals. The rest magma solidified soon after intrusion.

STRATIGRAPHY OF THE PHOSPHORIA FORMATION IN PART OF SOUTHWESTERN MONTANA

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In much of southwestern Montana the Permian Phosphoria formation is divided into five members. These are, in ascending order, a quartz sandstone-dolomite (not discussed), a thin lower phosphatic shale, a dolomite-chert, an upper phosphatic shale, and a chert-quartz sandstone.

The lower phosphatic shale member is 30 feet thick immediately west of Lima, Montana, but it thins to a featheredge 60 miles to the north and east. A thin basal phosphate bed in this member is continuous over most of the region.

The dolomite-chert member is 290 feet thick immediately east of Lima. Bedded chert constitutes the lower 110 feet. The dolomite grades westward into dolomitic sandstone, and both chert and dolomite thin northward and eastward, as the sandstone beds become more prominent.

The upper phosphatic shale member is generally 60 to 80 feet thick, but it ranges from possibly 150 feet west of Lima to 5 feet in the east. The thickness of the member is governed largely by the amount of fine-grained detritus. The phosphate content, however, is independent of the abundance of fine-grained detritus.

The chert-quartz sandstone member is slightly more than 100 feet thick. Facies changes between

chert and sandstone are common and abrupt. Chert may intertongue with or grade laterally into mudstone on both the extreme east and the west.

Members behave as units, and facies changes occur largely within rather than between members. The source of fine-grained detritus is not known, but quartz sand was apparently derived from the east, northeast, and west.

CAMBRIAN STRATIGRAPHY OF THE EAST FLANK BIGHORN MOUNTAINS, JOHNSON AND SHERIDAN COUNTIES, WYOMING

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Cambrian rocks along the east flank of the Bighorn Mountains range in thickness from 1130 feet at the north to 750 feet near the south. The rocks range from late Middle Cambrian through late Upper Cambrian (Trempealeauan). Three lithologic units are recognized for which formational names, all new to this area, are extended from western Wyoming to replace the name Deadwood now applied to these rocks. From top to bottom the units are named Grove Creek limestone, Gros Ventre shale, and Flathead formation.

The basal Flathead ranges from 300 to 450 feet in thickness; it is composed of sandstones to the south and sandstones with a thick (180 feet) middle shale unit to the north. A late Middle Cambrian *Ehmania* fauna is present near the top of the Flathead in the northern Bighorns.

Overlying the Flathead is the Gros Ventre shale with numerous intercalated thin sands and limestone flat-pebble conglomerates. The Gros Ventre ranges in thickness from 570 to 690 feet. In the northern Bighorn Mountains *Tricrepicephalus* was found 160 feet above the base of the Gros Ventre demonstrating that the Gros Ventre of the eastern Bighorns, unlike that of western Wyoming, is in part Middle Cambrian but is mostly Upper Cambrian.

The uppermost Cambrian unit, the Grove Creek limestone, is a sequence of gray thin-bedded limestones, limestone flat-pebble conglomerates, and a few very thin calcareous shales. The sequence thins southward; it is 160 feet thick near Sheridan, Wyoming, and becomes progressively thinner to the south and is absent near Mayoworth, Wyoming. The thinning of this unit is of depositional and erosional nature. The lower part carries some Franconian trilobites, while the top 20 feet contains *Symphysurina*, which is indicative of either Trempealeau or Lower Ordovician time.

STRATIGRAPHY AT AINSWORTH, KOOTENAY LAKE, BRITISH COLUMBIA

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Detailed remapping of a square mile of the Ainsworth mining camp has revealed that complexities of rock distribution are caused in part by abrupt facies changes and by granitization, rather than entirely by complex folding as was previously suggested. Rice's assignment of the Princess and Ainsworth formations to the top of the Lardeau group appears valid, but the overlying Josephine formation resembles no other stratigraphic division along Kootenay Lake. The Josephine comprises graywacke, chlorite-mica schist, quartzose limestone, quartzite, and beds, lenses, and bands of hornblende schist, in part forming a stratigraphic succession, but showing marked intertonguing and intergradation. Schofield's definition of the Josephine formation is amended to include the lower part of a thick graywacke unit and to exclude schists, argillaceous rocks, and limestone overlying the uppermost band of hornblende schist. The Ainsworth-Josephine contact appears to mark an abrupt change in the character of sedimentation and may represent a disconformity. Determinate fossils are lacking, but regional evidence suggests that the Princess, Ainsworth, and Josephine formations are Paleozoic.

SULFUR ASSOCIATED WITH PETROLEUM

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Deeper exploration for petroleum has found reservoirs with relatively high H_2S content in the gases. This dates from 1946 with the discovery of oil and gas in the Phosphoria formation of Permian

age at River Dome near Worland, Wyoming. The occurrence of such sulfur-rich gases is usually at a depth exceeding 6000 feet and in or adjacent to carbonate rocks. H_2S percentages range from 7 per cent to over 50 per cent in rare cases, representing recoverable native sulfur of 4 to 14 long tons per million cubic feet of gas. Distribution and occurrence of reservoirs containing both hydrogen sulfide and hydrocarbon gases are described briefly with Big Horn Basin fields being considered in greater detail. Origin of such deposits is interpreted as entirely organic, and their continued existence is expected, due to lack of modifying effect of subsurface waters which is common to shallower reservoirs.

CYLINDRICAL STRUCTURES IN PERMIAN (?) SILTSTONE, EAGLE COUNTY, COLORADO

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In East Brush Creek, Colorado, a calcareous siltstone bed 16 feet thick contains numerous cylindrical structures. The bed is 122 feet below the arbitrary base of the Triassic "Bright Red" siltstones, 760 feet thick. A 230-foot maroon sequence directly beneath the "Bright Red" is characterized by coarse-grained quartzites, arkosic conglomerates, and limestone intraformational conglomerates interbedded with limestones and calcareous siltstones. Irregular bedding, local cross-bedding, channeling, and rapid facies changes are also present. This sequence probably represents continental flood-plain conditions as opposed to the littoral or shallow environment indicated for the 8000 or more feet of underlying Pennsylvanian Maroon formation. The cylindrical structures are all perpendicular to the bedding. Their composition is identical with that of the rest of the bed. Cylinder contacts are sharp and somewhat irregular, although a general circular plan and uniform diameter are maintained throughout the length of the cylinder. Diameters range from less than 1 inch to 2 feet. The structures cross the crude bedding indiscriminately, and all seem to extend to the base of the bed. They are erratically distributed but are confined within several hundred feet along the outcrop. The cylinders are interpreted as fossil springs or quicksand pipes in a small area of semi-compacted surface mud. The bedding within pipes was destroyed by particle flotation in meteoric water rising under local hydrostatic pressure from a channel or aquifer at the base of the bed.

RELICT DIKES AT CORNUCOPIA, OREGON

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Dikes of many kinds are well exposed on the steep mountain sides and in the extensive underground workings of the old gold mines at Cornucopia, in the southeastern part of the Wallowa Mountains in northeastern Oregon. They comprise: the large conspicuous basalt and diabase dikes of Tertiary age, replacement dikes related to either an advancing or retrogressive stage of the late Mesozoic granitization, mobilized replacement dikes, and rheomorphic dikes. In addition there are narrow tabular bodies surrounded by essentially directionless granitic rock, and these dikelike masses are definitely older than the granitic rock.

They are of two kinds: (1) ribs of feldspathized schist and (2) tabular bodies, which, on casual inspection, could easily pass for dikes of porphyritic granodiorite. They are, however, penetrated by small apophyses of the surrounding granodioritic rock, and thin sections taken from border specimens show cusplike contacts, which are in part gradational with the dike minerals spreading into the granitic rock. Also along the borders poikiloblastic textures in the granitic rock show included dike minerals.

Since these dikelike bodies are older than the granitic rock they are probably best explained as relict dikes representing feldspathized bands or earlier dikes which acted as resistors to the later widespread granitization of the metamorphic rocks.

RELATIONSHIP BETWEEN THE DAKOTA AND FALL RIVER SANDSTONES IN SOUTH DAKOTA

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The Dakota sandstone was named by Meek and Hayden in 1866. The type area is in extreme northeastern Nebraska. The name was extended for use around the Black Hills by Darton and others.

In 1928, Russell noted that plants in the so-called Dakota of the Black Hills were of Lower Cretaceous age; he suggested the use of the term Fall River sandstone in the Black Hills area. Stratigraphic relations between the Dakota and Fall River have been obscure because of inadequate subsurface data. It has been the practice in subsurface correlations to call the first artesian sand the Dakota.

Sample and electric logs of recently drilled wells in central South Dakota have clarified the relationship. The Skull Creek shale, which overlies the Fall River, may be traced eastward into east-central South Dakota. The Fall River, which may also be traced into the same area, has previously been correlated with Jurassic or older sandstones. The true Dakota overlies the Skull Creek. It may be traced westward to the west-central part of the State, where it interfingers and wedges out into upper Graneros shale.

The interval between the tops of the Dakota and Fall River sandstones varies between 430 and 500 feet over the area where both are recognized. Previous structure maps have been drawn on the Dakota in the east, and on the Fall River in the western part of the State. Contours drawn consistently on the Fall River shift the axis of the Lemmon syncline eastward.

CAT CREEK OIL FIELD, PETROLEUM AND GARFIELD COUNTIES, MONTANA

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The Cat Creek Oil Field of Central Montana is one of the oldest and most prolific oil fields of Montana. However, the physical characteristics of the crude, its method of entrapment, and stratigraphic position are anomalous to "normal" oil fields.

The early use of excessive faulting to explain the field cannot be substantiated by studies resulting from more recent exploration. Structural evidence seems to indicate a shifting of the subsurface axis toward the steep northern limb of the anticline.

It is concluded that the Cat Creek Field has not been completely studied or evaluated and that such a study might lead to finding additional small, shallow oil pools and to a better exploration program for adequately testing the deeper Paleozoic section.

Structural conclusions made for the Cat Creek Field may extend to other structural features throughout Central Montana, causing their re-evaluation for possible hydrocarbons.

GEOLOGIC USE OF ELECTRIC LOGS

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A distinction is drawn between geologic use and engineering application of electric logs. Geologists not in the oil and gas industry may inadvertently assume that use of electric logs is limited to petroleum. On the contrary, problems are presented which involve sedimentation, structure, and stratigraphy, and which indicate that electric logs can be used in many avenues of research, even though they are best known in connection with work on petroleum and ground water.

Application of electric logs to engineering is illustrated by presenting the electric log, micro-log, radioactivity log, and core graph for a given productive well.

PHOSPHATIC ROCKS IN THE CENTENNIAL RANGE, MONTANA-IDAHO*

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This preliminary report describes the phosphate rocks of the Phosphoria formation (Permian) in the Centennial Range of southwestern Montana and adjoining parts of Idaho. In the Centennial Range the Phosphoria formation is divisible into five members, here designated A to E from the bottom to the top. The B and D members contain phosphate rock; most of the commercially important phosphate deposits are in the B member.

The phosphate rock of the B member is composed mostly of detrital material believed to have been deposited near shore; in places it may have been deposited as a beach. Abrupt transitions from phosphate to carbonate rock are visible in the outcrop of this member, and locally a conglomerate occupies its stratigraphic position. The B member is absent in the western part of the Centennial Range.

The detrital phosphate rock contains collophane particles of mechanical or chemical origin that are cemented mainly by collophane and less commonly by francolite. (Collophane and francolite are considered varieties of fluorapatite.) The particles are ovules, oölites, and fossil fragments; ovules are most abundant. Some detrital quartz and chert are present, and the replacement of collophane by quartz was observed. Common minor constituents include calcite, dolomite, muscovite, clay minerals, and limonite.

The phosphate rock of the D member is composed of collophane oölites or ovules with collophane or francolite cement. The phosphate rock of this member contains more oölites and less impurities, such as quartz, than the B member.

GROUND-WATER ALTERATION OF WESTERN COKING COAL

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Recent studies of coal in the Mount Gunnison quadrangle, near Paonia, Colorado, have provided data on the geologic environment of coking coal. The existence of coking and noncoking coal in adjacent areas of the same coal bed is indicated by chemical analyses and confirmed by physical tests. Coking coal was found only in an area of relatively stagnant ground water, below the water table. Noncoking coal was found in the zone of active circulation, near or above the water table. Destruction of coking properties is attributed to oxygen absorbed from circulating underground water. The present distribution of coking and noncoking coal in Carbon and Emery counties, Utah, is likewise attributed to differences in the circulation of underground water.

GYPSUM-OOLITE DUNES OF THE BONNEVILLE DESERT, UTAH

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A series of large lateral dunes occurs on the eastern margin of the Bonneville desert in the vicinity of the town of Knolls, Tooele County, Utah. Microscopic and mechanical analyses of the dune material show a mixture of oölites of various shapes, and gypsum crystals. The lithological type distribution of the component minerals in terms of grain-size distribution is illustrated by histograms. In addition, the dunes contain abundant identifiable ostracode carapaces, which are described and illustrated.

GEOLOGY OF THE NORTHERN PORTION OF THE BOULDER BATHYLITH, MONTANA

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The Boulder bathylith extends along the Continental Divide from Mullan Pass on the north to Divide 20 miles south of Butte. Its exposed area is about 1100 square miles. During the present

* Publication authorized by the Director, U. S. Geological Survey

work the northern portion of the bathylith and its enclosing rocks were mapped on the scale of 1:24,000 to obtain fundamental data on the contact metamorphism exerted by the bathylith and the mechanics of emplacement.

The oldest rocks are Belt formations; in ascending order, Spokane; Empire, 1000 feet thick; Helena dolomite, 4000 feet thick, chiefly siliceous dolomites carrying Collenia reefs from bottom to top; Marsh formation hitherto said to be 300 feet thick but in reality 3000 feet thick; and Greenhorn Mountain quartzite. Disconformably above the Belt strata are 9000 feet of Paleozoic and Mesozoic beds. Above these, separated by a disconformity representing an interval during which erosion cut down to the Quadrant formation, is a thick series of andesites and latites that constitute imposing remnants of the bathylithic roof.

These rocks were folded during a late Laramide orogenic phase, and the bathylith was emplaced, locally crowding the enveloping strata aside and even overturning them. The order of intrusion is (1) basic hypersthenic granodiorite; (2) granodiorite; (3) porphyritic quartz monzonite; (4) "white granite"; (5) muscovite-biotite granite; and (6) alaskite and aplite. True monzonite occurs at Priests Pass, and syenodiorite northwest of Helena. Only one lamprophyre, vogesite, is known.

The Boulder bathylith has exerted extensive metamorphism. Roof pendants of andesite have been altered to dioritelike rocks, and latite simulates flow-banded rhyolite. Superb cordierite hornfelses were formed, and immense volumes of tremolitic and diopside hornfelses were developed. The maximum rank of metamorphism is attained in sillimanite-cordierite-microperthite hornfels. The magma in places reacted with limestones, exometamorphically and endometamorphically, and locally produced nepheline shonkinite.

BITUMINOUS SANDS IN PLEISTOCENE DRIFT NEAR BUFFALO NARROWS, SASKATCHEWAN

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Small exposures of bituminous sand occur on both shores of the narrows of Peter Pond Lake, near Buffalo Narrows, Saskatchewan. These sands have been interpreted by various investigators as: (1) Outcrops in place of the bituminous facies of the Lower Cretaceous McMurray formation, which is exposed as the "Athabasca tar sands" in Alberta, 90 miles to the northwest; (2) Large blocks of "Athabasca tar sand" bodily transported by the ice and incorporated in the drift; (3) "Nests" of glacial sand in the boulder clay, which later became impregnated by bitumen due to oil seepage.

Extensive trenching indicated that the bituminous sands lie in boulder clay and do not represent outcrops of older formations. The sands occur in well-defined lenses with sharp boundaries. Underlying sediments show no traces of bitumen. Mechanical analyses and heavy-mineral suites are closely similar to those of representative samples of the McMurray formation. They are different from those of glacial sands locally present in the boulder clay.

It is therefore concluded that the bituminous sands are large bodies of "Athabasca tar sand" transported by the ice. Maps showing extensive areas including western Saskatchewan as underlain by the bituminous facies of the McMurray formation are probably in error. The direction of ice movement during at least part of the Pleistocene was from the northwest, and not only from the northeast as previously assumed on the basis of glacial striae in near-by areas of the Precambrian Shield.

DRUMLINOIDAL FEATURES OF THE NORTHERN MONTANA PLAINS

Robert M. Lindvall and Roger B. Colton

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The discovery of several areas of drumlins, drumlinoidal ridges, and drumlinized till in the glaciated plains section of northern Montana has made possible new interpretations of the direction of glacial ice movement in the region. Drumlins have been found near Kevin, Shelby, and Big Sandy. Drumlinoidal ridges formed in the lee of igneous dikes occur a few miles south of Virgelle. Areas of drumlinized till occur near Big Sandy, Havre, Chinook, Dodson, Fort Belknap, Sun Prairie, and Hinsdale.

CLIMATE OF WESTERN SOUTH DAKOTA DURING THE OLIGOCENE EPOCH

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Although the White River Badlands of South Dakota are one of the most productive sources of fossil mammal remains in the world, there is a surprising paucity of fossilized plant material. The fossil flora of a formation is our chief indicator of the past climate.

The only biological climatic indicators from the White River Group are *Celtis* the hackberry, *Juglans* the walnut, alligators, and land tortoises. At present these forms are concentrated in the Mesothermal or "C" climates of the Koeppen system. Alligators are found in Cfa and Cw climates, and the closely related crocodiles in Af, Aw, Cs, Cfa-b and Cw areas. Under special conditions they also live in the Bw climate of the Nile Valley. The Testudinatidae are typically Af, Aw, Cs, Scf-b, and Cw in distribution with a restricted range in Bs and Bw areas as waif elements.

The focal point of these distributions is the Cfa-b and Cw climates. The Cw or Mesothermal Savanna is found today only on east coast adjoining Aw (Tropical Savannas) or in highlands within Aw areas. It seems logical, on the basis of our admittedly inadequate climatic indicators, to postulate a Cfa-b climate for South Dakota during the Oligocene. We could then expect the following conditions to have existed:

Temperature range: Coldest month between 18°C and −3°C, warmest month over 22°C or below 22°C with four months over 10°C.

Rainfall: all seasons, 20–60 inches.

Vegetation: Mixed broad-leaf deciduous and evergreens with some conifers.

The climate probably was very much like the warmer portions of our present day Cfa climate in Louisiana and Mississippi.

PLACER DEPOSITS OF RADIOACTIVE MINERALS IN VALLEY COUNTY, IDAHO*

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A reconnaissance study was undertaken for the Atomic Energy Commission to provide a geologic interpretation of some placer deposits in Valley County, Idaho, drilled by the U. S. Bureau of Mines in 1951. The chief placer minerals are monazite and a group of uranium-bearing rare-earth columbates and tantalates (hereafter referred to as radioactive black minerals). Three dredges are now in operation on monazite placers in Long Valley, Idaho; deposits containing monazite and radioactive black minerals in Bear Valley will be opened in the near future.

The monazite is a widely distributed accessory mineral in the granitic rock of the Idaho batholith. The radioactive black minerals originate in pegmatite dikes that cut the granitic rock. Only locally are the amounts of these minerals in the bedrock sufficient to permit the formation of commercial placers.

A second essential requirement for the formation of a placer deposit is a concentration of the minerals in the soil mantle by selective weathering prior to their movement to the streams. All the known concentrations in soils are in areas that escaped glaciation during two late Pleistocene stages.

Deposits suitable for mining by large dredges are valley fills formed as a result of Pleistocene block faulting, fills formed by damming of streams by glaciers or glacial outwash during the late Pleistocene, and/or fills formed by aggradation due to an increase in load caused by accelerated erosion under periglacial climatic conditions. The typical valley fill consists of intertonguing depositional units of different origins. Other things being equal, the degree of concentration of the placer minerals in a given depositional unit is inversely proportionate to the rate of aggradation.

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* Publication authorized by the Director, U. S. Geological Survey

URANINITE-BEARING FINE-GRAINED PEGMATITE OF THE CHARLEBOIS LAKE AREA, NORTHEASTERN SASKATCHEWAN

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The uraninite-bearing deposits of this area are unusual and important concentrations of uranium. Discovered in 1949, they have been investigated partially. Diamond drilling has indicated some large low-grade bodies.

The deposits are in zones bordering granite masses that intrude folded Precambrian sediments. These zones are migmatites of calcium-rich sedimentary schists intruded and replaced by a fine-grained (¼ to ¾ inch) pegmatite. The most abundant facies of the pegmatite contains feldspar which is chiefly intermediate to basic oligoclase. A second is microcline-rich, but also contains oligoclase. In both quartz and biotite are other abundant minerals. A third facies is high in quartz due to replacement of feldspar. Parts of all three facies are end fractions relatively rich in fine-grained disseminated uraninite, which are the bodies of economic interest.

The plagioclase of the pegmatite is more lime-rich than those in the granites of which it is an end differentiate. This extra lime, evidently derived from the intruded sediments, would result in the raising of the temperature of crystallization of the pegmatite-forming magma, thus consolidating it rapidly near the granite contacts as a fine-grained pegmatite. The end liquor containing uranium was evidently locally concentrated in minor fracture zones in these pegmatites. Where no lime sediments were present, the coarse-grained alkaline pegmatites were formed. Their crystallization would not be accelerated, and the uranium would tend to migrate and consolidate at lower temperatures with the end products, possibly in some instances as pitchblende veins.

LONG-JAWED GOMPHOTHERID MASTODON FROM MONTANA

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In April 1951 an almost complete skeleton of a mastodon of questionable geologic age was recovered from sands and gravels of a terrace 150 feet above the Clark Fork River near Deer Lodge in Powell County, Montana. Preliminary field investigations suggested that the enclosing sediments might be chronologically related to late Pleistocene glacial deposits at the foot of the Flint Creek Mountains to the west. Recently more detailed investigations revealed that the bone-bearing gravels are distinctly older than those capping the terrace and are almost certainly of Tertiary age. Identification of remains found in association with those of the mastodon as the rhinoceras, *Teleoceras*, indicates that the bone-bearing gravels are Pliocene.

Bunomastodont molars, long lower jaw and symphesis, and long, worn, lower incisors place this mastodon in the group of "shovel-tuskers". A single molar in each side of the mandible, and the partial development of a sixth cross-lophid on each molar are outstanding characteristics of this Montana specimen. Mandibles of similar dimensions which have been figured and described to date are somewhat less advanced as to molar development.

GEOLOGY OF THE BRIDGER RANGE, MONTANA

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In and near the Bridger Range, in Gallatin County, just north and east of Bozeman, Montana, is exposed about 27,000 feet of sedimentary rocks, ranging in age from Beltian to Recent. A brief description of the areal geology is presented. Structural relationships within and near the map area are complex and suggest movements in two phases, in different directions. An illustration of the evidence for this conclusion is presented in the discussion of the Cross Range fault.

Middle Cambrian Flathead sandstone is underlain by coarse Beltian arkoses in the northern half of the range, and by Archean (?) metamorphics in the southern half. The depositional edge of the arkoses was fault controlled.

The steep western faces of the range are discussed, and reasons for interpretation of them as fault-line scarps are presented. This prolonged period of normal faulting began in the Oligocene and has continued to Recent time.

PETROLOGY OF SOME APLITES OF THE BOULDER BATHOLITH

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Gently dipping sills and small stocks of aplite occur in large numbers at many places in the Boulder batholith between Helena and Boulder, Montana. Systematic differences of texture and structure indicate that several suites of aplites may be present. The mineralogical and chemical compositions of these rocks are remarkably uniform. The ratio between quartz and the feldspars of the aplites is essentially the same as that of the quartz monzonite—the dominant rock of the batholith in this area. Chemically, the aplites are best classed as alaskite-aplites.

The aplites are xenomorphic and usually fine- to medium-grained. Small and irregular volumes within most intrusive bodies of the largest suite of aplites have textures like those common to pegmatites. These volumes show a variety of granophyric and graphic intergrowths as well as simple xenomorphic texture and are of coarser grain than the aplite host. Many of these pegmatitic volumes have a zonal arrangement of constituent minerals and of textures. Most of these pegmatitic textures are thought to be the result of direct crystallization from aplite magmas governed by slight fluctuations in rate of temperature change, coupled with local concentrations of hyperfusibles.

STRATIGRAPHY OF THE FOUNTAIN AND CASPER FORMATIONS IN THE SOUTHERN PART OF THE LARAMIE BASIN, SOUTHEASTERN WYOMING AND NORTH-CENTRAL COLORADO

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Five surface and three subsurface sections of the Fountain and Casper formations were described and correlated throughout the southern part of the Laramie Basin in Albany County, Wyoming, and Larimer County, Colorado. Samples from the surface sections were examined microscopically, and a sieve analysis was made of 93 surface and 5 subsurface samples. The sieve analysis showed an extremely well-sorted zone in the upper part of the Casper. Near the Wyoming-Colorado boundary this unit is 135 feet thick, and it thins toward the north and east.

Sediments of the continental Fountain formation and the marine Casper formation intertongue. The Fountain consists of sandstones and arkosic grits with minor amounts of shale and limestone; rests on Precambrian rocks in the Wyoming-Colorado boundary vicinity; and thins to the northeast, being replaced by the Casper, which rests on the Precambrian rocks in the vicinity of Laramie, Wyoming. The Casper formation consists of 100 feet of massive sandstone at the Wyoming-Colorado boundary vicinity; a middle shale unit is present at Centennial Valley; and in the vicinity of Laramie, Wyoming, it consists of 600 feet of interbedded sandstones and limestones.

STRUCTURAL DEFORMATION IN THE WILLISTON BASIN

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The earliest definite period of strong deformation in the Williston basin is Precambrian. In the eastern portion of the basin Precambrian trend directions are roughly east and west and may be considered spurs off the Canadian Shield. Trend directions may swing somewhat from the southeastern portion of the basin northward around the edge. These old structural remnants may be related to the late Precambrian tectonic forces which produced the east-trending structures in the Lake Superior region. In the southeastern part of the basin, northwest and southeast spurs of Precambrian highs strike off the major east and west trends, and in Canada the spurs may trend somewhat southwest. In the Canadian area the spur development seems to be less pronounced than to the south, and directions are not so definite. Some of these spurs may be Precambrian erosion highs, but they have influenced later Paleozoic structure. A probable late Devonian–pre-Mississippian deformation apparently took place, but data are meager. The post-Mississippian–pre-Triassic deformation is most significant insofar as basin structure in concerned. This deformation probably was related to and part of the Appalachian revolution. The direction of folding probably was influenced by pre-existing directions of weakness. The Nesson and Cedar Creek anticlines appear to antedate the Appalachian deformation and were probably pre-Mississippian–late Devonian although they may be Ordovician or older. Structural contours on the top of the Mission Canyon on the Nesson anticline show closure with the structure plunging southward. This direction of plunge is reversed in the post-Mississippian beds owing to change in thickness of the later sediments. Contours on Jurassic and Cretaceous beds show closure and southward plunge. A post-mid-Cretaceous period of warping likewise occurred which again was primarily a reflection of previous trends. These Cretaceous structures are probably related to Laramide forces. Deformation in the Tertiary beds in the form of folds and considerable faulting completed the development of the local tectonic elements of the basin. Some of the Tertiary faults, although showing displacements of usually only tens of feet, may extend to considerable depths and may be related to deep-seated faults. However, many faults appear to be confined to the surficial beds. This is true even of some with as high as 100 feet or more displacement.

SILURIAN STRATIGRAPHY OF THE WILLISTON BASIN

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Beds of Silurian age are difficult to separate from beds of uppermost Richmond age because they form a depositional unit, present in all except the southernmost portion of the Williston Basin. These beds had a much greater extent at the close of Niagaran time than they do today, and are lithologically and faunally correlative with beds of like age in the eastern part of the continent. The position of their present edges closely approximates the outline of the United States portion of the basin. Only on the northeast flank of the basin, in southern Manitoba, do these beds crop out.

This unit may be divided into three facies. The most widespread is that deposited on the stable shelf, consisting of clean, light, fossiliferous-fragmental, biostromal and normal marine limestones, almost wholly dolomitized, and some primary dolomite. This facies grades laterally into a basinal facies, occupying an area approximating the central part of the present basin, which consists of brown to black, bituminous, dense dolomite, nodular in part, grading to and interbedded with more or less of the shelf-type dolomite. A facies confined to the southernmost part of the area occupied by these beds indicates the approach to a shore line. Here the shelf-type dolomites are muddy and highly sandy, the clastic ratio increasing southward.

These beds underlay the eastern quarter of Montana, and oil is presently produced from them in three localities in this State.

ALGAL ZONES IN THE BELT SERIES IN THE GLACIER NATIONAL PARK REGION, MONTANA

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The Belt series in the Glacier National Park region consists of approximately 30,000 feet of unmetamorphosed sediments. Fossil algae occur in profusion throughout this mass of sediments. The fossils are similar in form to algal colonies growing today along the great Bahama Bank and to colonies that grew along the shores of Lake Lahontan during Pleistocene time. The algae of the Belt differ from more recent forms only in their apparent lack of microstructure. As a result, the species are based upon the gross form of the colonies. Several species are included in the one form-genus *Collenia*, known to occur in the area studied.

Seven algal zones have been recognized in the area: (1) the *Collenia columnaris* zone in the Altyn limestone of Willis; (2) the *C. symmetrica* #1, (3) *C. frequens* #1, and (4) the *C. willisii* zones in the Siyeh limestone of Willis; (5) *C. undosa*, (6) *C. symmetrica* #2, and (7) *C. frequens* #2 zones in the Missoula group of Clapp and Deiss. The limits of the Missoula group in Glacier National Park were modified by C. P Ross in 1949. The zones, characterized by one or two distinctive species, serve as good horizon markers for local correlation. Further work in neighboring regions should prove the usefulness of these and possibly other algal zones for correlation over larger areas, in addition to expanding our knowledge of the paleogeography of that time.

STRUCTURAL FEATURES OF THE WEST SIDE OF THE BOULDER BATHOLITH AND NOTES ON THE CHEMICAL PETROLOGY OF THE BATHOLITH AND RELATED ROCKS

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Late upper Cretaceous warping and erosion preceded outpourings of lavas and minor amounts of pyroclastics over the area of the western margin of the batholith. Post-volcanic deformation produced gentle warping followed by thrust faulting in contrast to the more intense deformations on the eastern side.

The batholith was emplaced after the thrust faulting and intruded close to the surface (5000 ± feet) over a large area without producing profound physiographic or foundering effects.

The western contact south from Elliston is essentially conformable to the enclosing volcanic rocks. Contact angles are low to nearly flat. In the southwestern part of the Elliston mining district, the batholith may be thin (500 feet or less). External and internal structures suggest a sheetlike or laccolithic body. Farther south, the outcrop pattern of the Warm Springs batholith is explained by north-south faulting of a nearly flat roof segment with the east side downthrown.

The intimate relationships of the pre-batholithic volcanics, the different petrologic facies of the batholith, and post-batholithic rhyolites are strikingly indicated on variation curves after Larsen. The chemical constituents of rocks from each group fall onto smooth curves. Analyses of rocks from the Philipsburg batholith and "Tertiary" intrusives in the Coeur d'Alene mining district, Idaho, fall on the same curves. Inadequate chemical data from the Idaho batholith do not necessarily indicate chemical consanguinity with the Boulder batholith.

ZEOLITES IN PEGMATITES AT DIVIDE-DEWEY CONTACT OF THE BOULDER BATHOLITH

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Small leucocratic dikes in granodiorite near the contact of the Boulder batholith between Divide and Dewey, Montana, have a wide variety of petrologic facies. The dikes grade from coarse, feldspar bodies with chlorite to aplitic and pegmatitic rocks, all in the same dike and locally in the space of a few feet. Some pegmatitic facies exhibit open spaces with well-formed crystals of adularia,

smoky quartz, and rarely black tourmaline. In several pegmatitic parts of dikes, complex crystal clusters of zeolites are derived from feldspar cyrstals. Calcite is commonly associated with the zeolites.

The leucocratic dikelets are small and discontinuous and are thought to represent residual concentrations in and adjacent to fractures formed during the cooling of the crystalline rocks. The latest deuteric solutions leached lime from plagioclase and altered the adularia to form the zeolites at moderately high temperatures as may be indicated by the small optic angles of the zeolites.

The optical properties of the zeolites are as follows: Heulandite 2 V = 5° (aprox) $n_\alpha = 1.495$, $n_\beta = 1.496$, $n_\gamma = 1.502$, $n_\gamma - n_\alpha = .007$; Stilbite 2 V = 5°–10° (variable) $n_\alpha = 1.495$, $n_\beta = 1.496$, $n_\gamma = 1.500$, $n_\gamma - n_\alpha = .005$; Chabazite (?) 2 V = 10° (more or less), $n_\alpha = 1.508$, $n_\beta = 1.508+$, $n_\gamma = 1.512\pm$, $n_\gamma - n_\alpha = .004$ (more or less).

HIGH-SILICA PORTION OF THE SYSTEM K_2O-FeO-Al_2O_3-SiO_2

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A preliminary phase diagram is presented in the form of a series of sections showing primary phase volumes at various FeO contents for that portion of the system having $K_2O + Al_2O_3 < 50$ weight per cent. Partial or complete quenching results have been obtained on approximately 250 compositions mostly concentrated in that portion of the diagram having $K_2O + Al_2O_3 < 25$ per cent. The primary phase volumes of leucite and fayalite are very large, while those of K feldspar and silica are surprisingly small. The diagram is complicated by the existence of 13 binary and ternary compounds, of which at least 6 show two or more crystal modifications each, and by the existence of two fields or phase volumes, each representing two immiscible liquids in equilibrium with one or more crystalline phases. No quaternary compounds have been found, but evidence points toward at least partial solid solution between $K_2O \cdot Al_2O_3 \cdot 2SiO_2$ (kalsilite and K-nepheline) and $K_2O \cdot FeO \cdot 3SiO_2$, and between $K_2O \cdot Al_2O_3 \cdot 4SiO_2$ (leucite) and $K_2O \cdot FeO \cdot 5SiO_2$.

REVISION AND EXTENSION OF THE SACAJAWEA FORMATION IN WYOMING AND MONTANA

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A distinctive red-bed sequence, usually considered the basal part of the Amsden formation, constitutes a persistent litho-stratigraphic unit over much of Montana and Wyoming. In most areas, this unit rests disconformably upon the Madison limestone, in many places filling channels and solution cavities, and forming part of a breccia matrix, in the upper Madison. In central Montana, it overlies the Heath formation of the Big Snowy group. It underlies typical Amsden carbonates, except in: (1) western Montana, where the Amsden is absent and the unit underlies the Quadrant quartzite, and (2) eastern Wyoming, where Amsden lithologies have not been separated from the Hartville and Minnelusa.

Thicknesses vary, without apparent pattern, from 5 feet in central Wyoming to 230 feet in the Big Snowy Mountains. Lateral and vertical variations between red sandstones, shales, siltstones, mudstones, and hematite pebble conglomerates occur rapidly; sandstone is generally near the base. The unit is primarily of Chester age, but may be older in part.

Because this red-bed unit is lithogenetically distinct from the rest of the Amsden, it should be recognized and mapped as a separate formation. The name Sacajawea, which has been applied to the Mississippian part of the Amsden in northwestern Wyoming, should be restricted vertically to include only the red beds, and extended laterally throughout the area where these beds are recognizable. The term Amsden should be retained for the limestones and dolomites between the Sacajawea (restricted) and the typical sandstones of the Tensleep or its equivalents.

THORIUM DEPOSITS OF THE LEMHI PASS DISTRICT, LEMHI COUNTY, IDAHO, AND BEAVERHEAD COUNTY, MONTANA

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Quartz veins, some of which contain thorite as a principal accessory mineral, occur over a 10-square-mile area in the Beaverhead Mountains, near Lemhi Pass, Lemhi County, Idaho, and Beaverhead County, Montana. The veins cut dark-gray to greenish-gray quartzites and argillites of the Belt series (Precambrian).

Green to gray-green dioritic dikes, which cut the quartzite, are the only intrusive rocks in the area. Tertiary volcanic rocks, which range from olivine basalt to rhyolite porphyry, are younger than the dikes and the quartz veins and overlie the Precambrian rocks on remnants of a well-developed land surface.

The quartz veins, which are chiefly along faults, range from a few inches in thickness and 100 feet in length to 30 feet in thickness and several hundred feet in length. These quartz veins are of four types, according to their principal mineral constituents: (1) those containing copper-bearing sulfides; (2) those containing hematite; (3) those containing barite, hematite, and thorite; and (4) those containing copper-bearing sulfides and thorite. The thoria (ThO_2) content of types 3 and 4 ranges from 0.1 to 2.0 per cent and averages less than 1 per cent.

The thorite-bearing quartz veins are associated spatially, and possibly genetically, with the dioritic dikes.

UTE MOUNTAINS, A LACCOLITHIC FEATURE IN SOUTHWESTERN COLORADO

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The Ute Mountains are one of the classic laccolithic mountain groups of the Colorado Plateau made famous by the reports of Gilbert, Peale, Holmes, and Cross. Though the general nature of these mountains has been known for a long time, detailed mapping of them has been undertaken only recently.

About 30 major laccoliths in two clusters form the Ute Mountains; in each cluster the laccoliths radiate from a central stock. The laccoliths are tongue-shaped masses ½ to 2 miles across and 1 to 4 miles long; some are faulted at their distal ends. The Mancos shale (Late Cretaceous) is the chief sedimentary rock invaded by the intrusive bodies. The shale is not markedly metamorphosed except close to the stocks, where it is moderately hornfelsitized. Mineralization was observed in only one laccolith and an adjacent dike. Most of the large dikes in the Utes trend northward and lie in a north-south zone that contains the two stocks and the mineralized laccolith. This orientation suggests that both igneous intrusion and mineralization were controlled by a deep-seated structure in the basement complex.

Around the southern stock most of the laccoliths were intruded at about the same stratigraphic horizon, near the base of the Mancos shale, and tend to overlap like a fan of cards. In the southern cluster the laccolith tongues cut downward in the section away from the stock.

SOME FEATURES OF THE PITCHBLENDE DEPOSIT AT THE COPPER KING MINE, LARIMER COUNTY, COLORADO*

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Uranium has been produced from a pitchblende-siderite vein at the Copper King mine, in the northern part of the Front Range, Larimer County, Colorado. The vein is along one of the easterly-

* Publication authorized by the Director, U. S. Geological Survey

trending faults of small displacement that cut Precambrian granite, anthophyllite-cummingtonite skarn, and biotite-quartz-plagioclase gneiss.

Pyrometasomatic deposits consisting of pyrite, sphalerite, chalcopyrite, pyrrhotite, and magnetite of Precambrian age occur in the skarn. The largest deposit is cut by an early Tertiary pitchblende-bearing vein.

In the upper levels the pitchblende is in a vertical well-defined, hard, tabular breccia zone; in the lower workings the pitchblende is in discontinuous, "horsetailing" fractures. At three places in the mine pitchblende also occurs in the interstices of boxwork pyrite.

The pitchblende ore forms a nearly vertical shoot, between 50 and 135 feet below the surface, that has a horizontal length of at least 50 feet and a thickness ranging from a featheredge to about 4 feet. The highest grade ore in the shoot is in pods and lenses as much as 25 feet long and a foot thick. Within the lenses the pitchblende occurs as (1) brecciated fragments less than an inch in size, (2) veinlets as much as 2 feet long and an inch thick, and (3) botryoidal masses about 1 mm. in diameter. The vein pitchblende is hard and is always intimately intergrown with siderite; minor gangue minerals include quartz and pyrite. The pitchblende in the boxwork pyrite is soft and sooty.

ANCIENT BURIED SOIL IN THE COLUMBIA RIVER LAVAS AT LEWISTON, IDAHO

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In Idaho the lowest elevation at which Columbia River basalts are exposed is at Lewiston at the point where the river enters Washington. Cuttings from the recently drilled Potlatch Forests, Inc. well, near the axis of the Lewiston syncline in these basalts, indicate an ancient soil horizon at an altitude of 440 feet, or 300 feet below the surface. The soil is 10 feet thick and overlies 10 feet of partly decomposed basalt. The soil is overlain with 20 feet of green shale, 232 feet of basalt, and 49 feet of alluvium. In the Camas Prairie Railroad well in Lewiston, the shale is 55 feet thick.

The soil indicates a long time interval when no lava flows reached this area and raises the question as to whether all the Columbia River lavas were erupted in one geologic epoch.

PHOSPHATE DEPOSITS OF PERMIAN AGE IN MONTANA

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Investigation of the Phosphoria formation (Permian) in Montana includes studies at some 50 localities, measurement of 10,000 aggregate feet of strata, and collection of 1500 channel samples. The five members of the formation include two phosphatic shale members.

The basal quartz sandstone-dolomite member is 350 feet thick near Lima, Montana, and 380 feet thick in the Snowcrest Range, but thins abruptly to 30 feet south of Dillon. It thins eastward and becomes indistinguishable from the underlying Quadrant quartzite. It is probably equivalent to the upper part of the Wells formation of Idaho. The member may be excluded from the Phosphoria in future descriptions, perhaps by raising it to formation rank.

The investigation also established regional relations of the other members. Recent work by Sheldon in Wyoming indicates probable correlation of the lower phosphatic shale member with the phosphatic shale member of the Phosphoria in Idaho. Where this shale is absent north of Dillon, the middle chert-dolomite member, correlative with the Rex chert member of the Phosphoria in Idaho, is inseparable from the basal member. The upper phosphatic shale member, not well developed in Idaho, is prominent and important in Montana. The uppermost chert-quartz sandstone member is regionally conspicuous in Montana. All members thin northward and northeastward. The Phosphoria is overlain on the south by the Triassic Dinwoody formation, at least locally unconformably, and on the north by rocks of the Jurassic Ellis group with more marked unconformity.

Both phosphatic shale members increase in phosphate content southward. Acid-grade rock of the lower phosphatic shale member is restricted to the Centennial Range. Phosphate of the upper shale member attractive to exploitation occurs only north of Dillon. Phosphate occurs as brownish-black oölitic carbonate fluorapatite interbedded with dark mudstones, locally oil-rich, whose thickness

and spacing control mining grade. Sandstone interbeds play a similar role in the Centennial Range. Besides the active Garrison and Melrose fields, economically attractive areas include the Centennial Range, Anaconda to Maxville, and Elliston.

STRATIGRAPHY AND PALEONTOLOGY OF THE OTTER FORMATION, MONTANA

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The Otter formation, of the Big Snowy group, is distributed throughout central Montana. The Big Snowy group represents the major portion of Upper Mississippian sedimentation in the central Montana trough east of the Cordilleran miogeosyncline.

Six measured outcrop sections of the Otter formation varied in thickness from 153 feet at Delpine, Montana, to 355 feet in the Little Snowy Mountains. The average thickness is approximately 300 feet.

The lithology of the Otter is characterized by gray to greenish-gray calcareous shales intercalated with a number of thin, persistent limestone strata which serve as excellent marker beds. These marker beds were encountered at all the localities studied except Three Forks where the section is poorly exposed. The repeated vertical alternation in lithologies, and lateral persistence of the marker beds, suggest that depositional environments were uniform over wide areas but were of short duration.

Of special interest in the Otter formation is the intimate association of oölites and "billowy" beds. The "billowy" beds probably represent algal deposits. The occurrence of algal limestones in the Otter has not previously been reported.

Approximately in the center of the Otter formation a fossiliferous zone contains a remarkable faunal assemblage of bryozoans, corals, gastropods, pelecypods, blastoids, crinoids, and brachiopods. While some of its forms attain their full size and development, especially the bryozoans, others are somewhat phenotypic.

DESIGNATION OF STRATIGRAPHIC UNITS

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A utilitarian "stratigraphic code" should be sufficiently flexible to permit freedom in selection and naming of units, should encourage the designation of stratigraphic and map units which fulfill the needs of each field of specialization, but should employ terms with uniform connotation in all fields.

Cases involving designation of stratigraphic units from Cambrian to Tertiary are cited which indicate that the above aims are attainable under the following conditions:

(1) All stratigraphic units (lithic, biologic, or chronologic) are potentially employable as map units, and provision should be made for such application. However, only rock units, because of their objectivity, are recommended for general use in cartography.

(2) Geologic maps based on these various kinds of units (or their combinations) should be labeled as to type, and their units designated accordingly. Biostratigraphic units, for example, should not be called "formations."

(3) Rock units may effectively terminate laterally by gradation, pinch-out, erosion, deep burial, and *arbitrary cut-off* (where a rock unit changes content and identity or rank without mappable lithologic contact). Recognition of the cut-off as standard procedure would indicate acceptance of the following items:

(4) All interfacies boundaries in stratigraphy are arbitrary cut-offs.

(5) A unit of one rank may retain its identity as parts of two or more units of greater rank.

(6) Intertongued members should be assigned to one or the other of the formations involved—not alternately to each. Vertically successive alternations of stratigraphic units, unless tectonically induced, needlessly compromise the Law of Superposition.

(7) The term "tongue" should be abandoned for formal rock-unit designation.

TERTIARY MINERALIZATION IN SOUTHERN BRITISH COLUMBIA

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Many important ore deposits in the Western States are in Tertiary rocks, genetically related to Tertiary orogeny. In contrast, most ore deposits of Southern British Columbia are in pre-Tertiary rocks, and their age is less certain. Usually mineralization is assigned a vague Jura-Cretaceous age based only on assumed genetic relations to contiguous Mesozoic intrusions.

However, although the Tertiary record is fragmentary, enough remains to indicate that the Tertiary history was marked by widespread vulcanism, alkalic intrusion, and strong crustal deformation—conditions favorable for the formation of ore deposits.

In this paper the Tertiary history of two areas of Southern British Columbia—the White Lake area of the Okanagan Valley, and the Greenwood-Grand Forks area—will be outlined. In these areas at least, important base-metal mineralization is believed to be related to mid-Tertiary orogeny. Other parts of Southern British Columbia will be noted which have similar geological conditions and in which there is a possibility that the ore deposits are of Tertiary age.

ABSTRACTS OF PAPERS PRESENTED AT THE MEETING OF SECTION E, AAAS, IN BOSTON, DECEMBER 28, 29, AND 30

PROBLEMS IN NEW ENGLAND PALEOZOIC STRATIGRAPHY*

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Correlation of fossiliferous, relatively unmetamorphosed strata with relatively unfossiliferous metamorphosed strata is an important problem in New England stratigraphy.

In Vermont, east of the Green Mountain anticlinorium, the Shaw Mountain formation may be of post-Ordovician, possibly Silurian, age if the Ordovician graptolites ascribed to the Tomifobia formation of Clark actually were derived from an older unit. The age of the pre-Shaw Mountain strata (thought to be Cambrian or Ordovician) above the Precambrian may be partly answered by studies now being made in the northern Green Mountains.

In New Hampshire strata beneath the Clough quartzite are thought to be Ordovician or possibly Cambrian. The precise correlations between the fossiliferous Silurian and Devonian strata of New Hampshire and their metamorphosed equivalents are not known.

In western Massachusetts the correlations are related to those in Vermont. East of the Connecticut River the correlations have been made with New Hampshire. In the Worcester region the problem of the Carboniferous age of the Worcester phyllite is connected with fossil plants that are misplaced. Another problem that should be considered is Bell's opinion that the Boston Bay group is of Late Devonian rather than Carboniferous age.

In Maine the chief problems are the pre-Middle Devonian stratigraphy of the unmetamorphosed strata in northern Maine and their correlation with northern New Hampshire, correlation of the metamorphosed strata in central and coastal Maine with beds elsewhere, and correlation of the coastal facies of the Silurian with that of northern Maine.

GEOCHEMICAL OXIDATION OF ROCKS

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There are different ratios between the negative mass (the sum of the atomic weights of the negatively charged ions) and the positive mass (the sum of the atomic weights of the positively charged ions) in composition of rock-forming minerals (magmatic, metamorphic, supergene). The positive mass prevails in magmatic minerals, the negative mass prevails in supergene minerals, and in metamorphic minerals the ratio between the mass of negative ions and the mass of positive ones is nearly 1. We call this ratio the coefficient of "geochemical oxidation", K.

It is convenient to express the chemical composition of a rock by means of a "chemical formula of a rock". Then the value of the coefficient K will express the degree (high, medium, low) of the "geochemical oxidation" of the rock. Thus, *e.g.*, it is possible to characterize magmatic rocks of the following evolutionary series: dunite, peridotite, gabbro, diorite, syenite, granite, by means of successively increasing K (dunite — K = 0.82, gabbro — K = 0.92, granite — K = 1). It is interesting to note that granites are very abundant rocks in composition of lithosphere, and, as their K is nearly 1, K for the upper part of lithosphere is also near 1. On the other side, as we know, the sum of percentage weight (clarke) for oxygen and other negatively charged ions in the chemical composition of the part of the earth's crust known to us is almost 50 per cent (*cf.* data of Clarke and Washington, Berg Vernadsky, Fersman).

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TREATMENT AND DISPOSAL OF WASTES IN ATOMIC ENERGY INDUSTRY

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The radioactive-waste problem differs materially from other waste-disposal problems. The human tolerance for most of the wastes in water is a small fraction of a part per million, and the total mass of the waste is very small. Disposal by dilution is not feasible for the highly radioactive fission products, but is possible for low-level wastes. Compared to other industries the cost of present waste disposal and storage methods is great. The cardinal points about the waste problem are: (1) the environment must be absolutely protected on a conservative basis from harmful contamination, and (2) within this limit environmental dilution factors should be made useful in the interest of economy.

This problem demands a knowledge of characteristics and movements of surface and ground water in much greater detail than is needed in water-supply work. The dynamics of streams must be understood in order to have some guidance as to mixing characteristics of the stream. The characteristics and properties of suspended sediments to adsorb radioactivity must be understood. Factors to be considered in underground disposal are: the lack of mixing in ground-water movement; the direction of flow, which is not necessarily along the hydraulic gradient; the effect of density of wastes; the possible evolution of heat by the wastes; the velocity of flow; the chromatographic phenomena due to various processes of adsorption; the consideration of these phenomena in the many types of geologic environments of present and future interest.

FURTHER EVIDENCE FOR TURBIDITY CURRENTS FROM THE 1929 GRAND BANKS EARTHQUAKE

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In 1952 Heezen and Ewing* concluded that the breaking of all submarine telegraph cables in sequence from north to south following the Grand Banks earthquake of 1929 could be explained satisfactorily only by supposing that a turbidity current, generated in the epicentral area, flowed southward breaking the cables as it reached them.

At the same time Kuenen† discussed the magnitudes involved. From the volume and density of turbid water necessary to account for the high velocity indicated by the timing of the cable breaks he calculated that a graded layer of relatively coarse sediment between 40 and 100 cm thick should have been deposited over a wide area south of the cable breaks. At that time no sediment cores from the area were available.

Since appearance of these papers, however, two cores from the area have been examined. Each contains a layer of graded silt and muddy sand overlying foraminiferal clay of abyssal facies. Recent deposition of the graded layers is indicated by absence of abyssal sediment overlying them. The thicknesses of the layers are 70 and 130 cm.

The writer concludes that the independent evidence afforded by the cable breaks together with the evidence from the cores confirming Kuenen's prediction add up to proof of the reality of turbidity currents as powerful agents of erosion, transportation, and deposition of sediment.

MONSON ORTHOGNEISS IN CONNECTICUT‡

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Emerson originally described the Monson granodiorite of central Massachusetts as having a simple equidimensional granitic texture with biotite and epidote as mafic minerals, feldspar entirely

* Heezen, Bruce C., and Ewing, Maurice, 1952. Turbidity Currents and Submarine slumps, and the 1929 Grand Banks Earthquake: Am. Jour. Sci., vol. 250, pp. 849–873.

† Kuenen, Ph. H., 1952. Estimated size of the Grand Banks Turbidity Current, ibid., pp. 874–884.

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plagioclase, and quartz as large rounded grains. Foye used the term Monson orthogneiss to include two bands, continuous from Wilbraham and Monson in Massachusetts to below Glastonbury and Haddam in Connecticut, respectively, an oval area around Killingworth, and an irregular area within the Hebron gneiss.

Recent work by Aitken about Coventry and Bolton Notch, and by Herz in the Glastonbury quadrangle, indicates a more complex petrography and origin for the Monson orthogneiss than Foye depicted. Aitken found the Monson and Hebron formations to be one structural unit, discordant to the formation boundaries drawn by Foye, and with complete gradation and mixing from one to the other. Herz mapped four gradational facies in the Glastonbury band, from west to east: a schistose gneiss against the western schist contact, a porphyroblastic gneiss representing maximum potash metasomatism, a flaser gneiss, and highly felsic gneiss against an eastern quartzite contact. In the Glastonbury quadrangle, the Glastonbury and the Haddam bands of the Monson were clearly distinguishable on the basis of abundant potash feldspar in the former.

The Monson orthogneiss in Connecticut, or at least its Glastonbury and Haddam bands, seems to be a product of granitization or migmatization rather than magmatic differentiation, as its equivalents in northern Massachusetts and New Hampshire, the Monson granodiorite and Oliverian magma series, are held to be.

INDUSTRY'S WATER REQUIREMENTS

Herbert E. Hudson, Jr.

Every industrial establishment requires some water. In many cases large requirements can be reduced to very small amounts by the employment of conservation techniques, but the cost of these techniques may affect the competitive position of the plant.

The earliest industrial plants located near streams or bodies of water for reasons of transportation, waste disposal, water power, and water supply. Earliest water demands were comparatively small, and water use methods simple. Once-through-and-waste was the rule. American industry is still accustomed to these methods which developed under conditions of dispersed plant location.

Both the demand and the supply situation, however, are now radically changed. As thermal processes came into greater industrial use, more water was needed for disposal of waste heat, and, with the development of mass-production techniques, more water was required as a conveying medium. Concentration of industrial areas has increased competition for water supply. Today, American Society has entered a phase of competition among industry, agriculture, and public water-supply needs for water.

This competition has led to initiation of conservation techniques of five general types: (1) control techniques, (2) recycling, (3) multiple or successive use, (4) substitution of source, and (5) non-evaporative cooling techniques. All these are being used, but in only a very few establishments have they been exploited fully. In these establishments reductions in water requirements as great as 98 per cent have taken place. One prominent trend has been toward substitution of sea water for fresh water for cooling.

The future calls for increasing application of these conservation techniques. Professional people skilled in their use will be required by industry, and it is expected that there will be a greatly expanding field of activity for engineering and chemical specialists in this line of work. Unless the techniques are mastered by a sufficient number of skilled persons, the reduction in industrial requirements cannot take place, and our social and economic development will be impeded.

INDICATIONS OF CRUSTAL UNREST ALONG THE SOUTHERN EDGE OF THE CANADIAN SHIELD

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That vast area of ancient igneous uplift which constitutes nearly all of southeastern Canada has long been known as the most stable part of North America. But evidence gleaned from four sciences

definitely indicates that the shield exerts a strong southward pressure on the rocks with effects that have both scientific and economic importance.

Seismology shows that major accumulations of stress exceeding the strength of the rocks repeatedly have recurred near the southern edge of the shield; that usually they were followed by minor seismic disturbances farther south; and that the earthquake movements were toward the south and southwest.

Geology describes two important lines or zones of crustal weakening and numerous minor structures whose forms and trends indicate that a strong southward pressure was the genetic force.

Mathematical calculations demonstrate that any appreciable southward movement of the shield must cause noticeable crustal warping. Both geophysics and geology supply abundant evidence which strongly supports this theory in two ways:

Repeatedly changes have occurred in the direction of drainage of Great Lakes waters to the sea. At one time a wide river flowed from Lake Michigan through the present site of Chicago southwestward across Illinois to the Mississippi River. And changes in the water levels of the Great Lakes have occurred at irregular intervals and despite the influence of wet or dry seasons. Beaches were widened, or shore lines were submerged with enormous total damages to property.

It is believed that these movements result from crustal creep. Outstanding authorities in several countries have urged there is a general, gradual slipping of crustal materials toward the equator because of forces set up by Earth's rotation.

WATER AND STEEL

Ross L. Leffler

This paper is concerned primarily with the water supply and water-treatment requirements of United States Steel Corporation's new integrated steel plant, the Fairless Works, located on the Delaware River at Morrisville, Pennsylvania. The paper describes briefly the water requirements of steel plants in general; then more specifically it discusses the water-supply system at Fairless Works and the wastes-water treatment facilities at this large steel plant.

Included in the paper is a discussion of the Fairless Works' three distribution networks, and also a description of the water, sewage, and wastes-treatment pumping installations.

HEAVY MINERALS IN THE REGOLITH AND SOILS MATERIALS OF MASSACHUSETTS

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Diagnostic heavy minerals were examined in samples of regolith and soils material from various parts of Massachusetts with special attention devoted to the Connecticut Valley.

In general epidote-zoisite, black opaques, amphiboles, and garnet are the most abundant minerals in the samples studied. Zircon, tourmaline, and muscovite are common. Chlorite, biotite, chlorotoid, rutile, sillimanite, kyanite, andalusite, staurolite, titanite, pyroxene, apatite, anatase, leucoxene, siderite, and limonite are less common to rare.

From west to east, Massachusetts can be divided into five general physiographic areas: the Housatonic-Hoosic River valleys, the Western Highlands, the Connecticut Valley, the Eastern Uplands, and the Eastern Lowlands. Because of differences in topography and bedrock from one region to another, certain local variations in the kind and frequency of heavy minerals were noted. Garnet is abundant in soil samples from both the eastern and western uplands and is present only in minor quantities in the Housatonic-Hoosic valleys. Sillimanite is fairly abundant only in the eastern upland samples and is rare to absent in samples from other regions. Amphiboles are abundant in samples from all regions except those from the Western Uplands.

The pattern of the heavy-mineral assemblages in the Connecticut valley indicates a common source for glacial materials and the soils there.

Detailed studies of several soil profiles from different areas show no significant variations in heavy-mineral content with change of horizon.

GEOLOGY OF A PORTION OF THE EAST-CENTRAL GEORGIA PIEDMONT

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The area discussed refers primarily to Clarke County, Georgia, where geologic mapping has been under way in co-operation with the Georgia Department of Mines, Mining, and Geology. The region is underlain by biotite-albite-oligoclase granites and gneisses which trend northeast. They are intruded by microcline granites, quartz monzonites, aplites, and hornblende diorites. Most of the rocks are thought to be Precambrian, although some intrusives may prove to be Carboniferous. A few Triassic (?) diabase dikes are locally exposed and strike across trends of other rocks. Mineral assemblages within the country rock are representative of the amphibolite facies. Quartz veins and lenses of several kinds fill foliation planes and fractures of all rocks except the diabase dikes. Strongly developed foliation parallels and, where recognized, lies at high angles to the bedding. Foliation usually strikes northeast and dips steeply to the southeast, while the remnants of major fold structures indicate a southwest plunge. The strike of lineation and flow structures in some rocks shifts from northeast to northwest across the area. Although petrographic studies have revealed some rare minerals, including monazite, it is not believed their quantities will prove sufficient for exploitation. Also the quality of the granites makes them unsatisfactory for use as a building stone.

AVAILABLE WATER SUPPLY IN UNITED STATES*

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The water resources of the United States are abundant when considered on a country-wide basis, but regional variations in precipitation, stream-flow and ground-water conditions have resulted in some serious water problems that will increase in number and severity in the future. Although there appears to be no overall trend toward increase or decline in the basic water supply for the Nation, the use of water has increased in some areas equal to or in excess of the local supply. Several methods for improving the supply situation, by modification of natural variations in supply or reclaiming water losses, are discussed. A study of municipal water shortage occurring during 1953 is presented, with an evaluation of causes. In most water-short areas, the potential availability of water is sufficient to supply future needs if the total water resources are developed on a basin-wide or aquifer-wide basis and if conservation methods are applied.

The industrial use of water is increasing faster than other uses and is expected to double within the next two decades. Most industrial uses are not highly consumptive, and many cycles of reuse of water are possible if pollution control and other conservation practices are given wide application. One of the major deterrents to solving water-supply problems is the deficiency in information on the occurrence and variation in the available water supply.

CORRECTION OF A FLUVIATILE DELINQUENT, THE SCHUYLKILL

Francis A. Pitkin

The Schuylkill Basin in southeastern Pennsylvania became the depository for wastes from municipalities, industries, and the anthracite coal-mining industry during a period extending over the last 130 years. Although attempts were made to remove municipal and industrial wastes during the past 50 years, the mining industry was left free to discharge into the river and tributary streams millions of tons of coal culm and silt from mining operations. In 1945 laws were enacted to stop the discharges. A co-operative program initiated by the Interstate Commission on the Delaware River Basin and adopted by the Commonwealth of Pennsylvania has entailed the expenditure of some

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six million dollars on the part of the mine operators to keep silt and culm out of the river; the expenditure on the part of the State government of about 35 million dollars for dredging the river above Norristown; and ten million dollars on the part of the Federal government to remove the deposits of silt and culm from the river below Norristown to the Delaware River.

The program was accepted by the three groups responsible, and corrective measures instituted to carry out the program. Mine operators have installed desilting works at the 44 operating mines which have reduced the discharges to about 50 tons of silt per day as contrasted with discharges of 5000 tons per day in 1946, a reduction of 99 per cent in the 7-year period.

The Water and Power Resources Board of the Pennsylvania Department of Forests and Waters authorized Admiral Milo F. Draemel, Secretary of the Department, to enter into engineering contracts with competent engineering firms to carry out directives for dredging the accumulated deposits of culm and silt from 86 miles of the river and restore it to its original bed and banks.

The program included supervision by the Commonwealth's Sanitary Water Board of culm, silt, and other waste discharges from the mines, industries, and municipalities, and investigations and studies of the effective results of the operations by the United States Geological Survey.

The responsibility for restoring the river to its original status from Norristown to the Delaware River was accepted as the responsibility of the Federal government represented by the United States Engineers Corps. The United States Engineers have received appropriations sufficient to finance their part of the desilting program of which about one-third is completed.

The restoration of the Schuylkill has been an outstanding example of what can be accomplished by co-operation by the various levels of government and by industry. Restoration of the river has resulted in substantial benefits to municipalities and industries for water supplies. Flood dangers have been decreased. Recreational potentialities of the river have been restored with substantial increases in boating, bathing, and fishing. Property values have shown increases due to the river improvement.

PLUTONIC ROCKS OF RHODE ISLAND*

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A co-operative geologic mapping program is being carried on between the United States Geological Survey and the Rhode Island Development Council. It is expected to yield a detailed geological survey of the State, by quadrangles.

At least three main groups of plutonic rocks are distinguished. The youngest group, including the fine-grained and medium-grained Westerly granite, are intrusive into Pennsylvanian sedimentary rocks of the Narragansett Basin and are, therefore, of late Pennsylvanian or post-Pennsylvanian age.

An older group includes Quincy granite, granite porphyry, and associated volcanic rocks. This group is correlated with the White Mountain plutonic volcanic series of New Hampshire on the basis of the structural relations and such minerals as riebeckite and aegirite; it is considered of Mississippian (?) age.

The oldest main group includes a considerable variety of granite, granodiorite, and quartz diorite. These rocks are older than the Quincy granite, younger than the Precambrian (?) Blackstone series, and have been assigned to a Devonian (?) or earlier age.

The Sterling granite gneiss is of controversial origin and age. Certain parts are clearly of metasomatic origin, and some may be of magmatic origin. Some may be related to the Westerly granite of Pennsylvanian or later age, and some may belong to the oldest group. Detailed mapping is being done to determine the origin and age of different parts of the area underlain by the Sterling granite gneiss.

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Of the three main groups, the two youngest appear to be magmatic. The oldest group and the Sterling granite gneiss seem to include rocks of both magmatic and metasomatic origin.

ANTICLINES AND DOMES OF THE WILMINGTON, VERMONT, AREA

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The Wilmington area of southern Vermont is on the eastern flank of the Green Mountain anticlinorium. The stratigraphic sequence comprises Precambrian gneisses and metamorphosed Lower Paleozoic clastic sediments and volcanics. They are separated from the Precambrian rocks by an angular unconformity. The gneisses and schists of the eastern flank of the anticlinorium form an easterly dipping homoclinal sequence complicated locally by small anticlines and larger domes The domes are 4–8 miles long and are found about 9 miles east of the Precambrian unconformity.

Small-scale structural features studied include minor folds, fold lineation, mineral and pebble lineation, quartz rodding, boudinage, and cleavage. These features are divided into two kinds, those of Sadawga and Ray Pond domes, and those associated with the Green Mountain anticlinorium. Those of the domes have attitudes the reverse of those of the anticlines.

The minor structures of the anticlines have attitudes which confirm the idea that the Green Mountain anticlinorium was formed by lateral compression. Those of the domes suggest that they were produced by vertical movements of the core gneisses relative to the overlying schists. The dominant minor structures of the domes indicate that the upper beds have moved toward the axis of the syncline relative to the beds below. Less prominent in the domes are minor structures which suggest a relationship to the Green Mountain anticlinorium. The relationship between these two associated but contrasting sets of minor structures indicates that the domes were formed subsequent to the folding of the Green Mountain anticlinorium.

WATER FOR THE FUTURE

J. R. Whitaker

Concern over the availability of water for American industry in the future grows out of the existence of areas of water shortage and the possibility that these areas will multiply and grow in size as water needs increase.

In spite of large national water resources, shortages of water for industry occur because water varies greatly from place to place and time to time, and because industrial demand is spot and line demand. A relatively wide margin of water above needs still exists in the East, but even there water is sharply localized, markedly fluctuating, and badly polluted. In the near future heavy water users will doubtless seek rich aquifers, large rivers, and lake and ocean shores; and industries with high-quality requirements will hunt ground waters and headwater streams, but the principal demand will remain in the American Manufacturing Belt. Over wide areas the readily available, low-cost water supplies have been developed. The supply of cheap water not needing beneficiation is running out.

Essential measures to keep water-short areas from multiplying and spreading in the near future are considered: location of industry, expansion of detailed data on resources, organization of water-supply systems, harmonizing competing uses of water, protection and improvement of waters, and more effective use of available supplies.

On the distant horizon loom other developments: increased demand for humid-land irrigation and new industries; new water sources, as from distillation of salt water and rain making; negative items as siltation of storage reservoirs, with progressive upset of industrial adjustments. This predicament will foster conservational management of water resources by river and ground-water basins.

EROSION LEVELS IN NORTHWESTERN MAINE

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A study of the landforms of the Rangeley Lake, Maine, region has been undertaken in an attempt to discover whether there are well-defined erosion levels in that area and, if so, how these might be explained. Careful analysis of topographic maps, combined with extended traverses into critical areas, demonstrates the existence of well-defined levels at the following elevations (feet): 1100, 1400, 1700, 1950–2150, 2400, 2700, 3000, and 3200–3300.

The predominant levels of the region are at 1700 feet and between 1950 and 2150 feet. All elevations noted are strikingly similar to those observed by other workers in Vermont and western Massachusetts.

The favored hypothesis for the multiple erosion levels separated by marked breaks in slope is that of fluvial erosion, under regional base-level control. Glacial action has been a minor factor, responsible for the modification of some levels, but not for their presence. No definite lithologic or structural controls for the various erosion levels were noted.

It is suggested that regional isostatic adjustment to the Acadian orogeny and to the subsequent erosion reached its conclusion at the end of the Cretaceous and that existent erosion levels are post-Cretaceous. The series of positive movements of the New England crust is attributed to subcrustal differential expansion rather than to isostatic adjustment. Intermittent negative movements are expectable, with the drowned New England coast line as obvious evidence. In terms of modern orogenic hypotheses, the rhythmic movements are explainable by the presence of a blister or convection cell beneath much of eastern North America.

TRENDS IN THE PATTERN OF INDUSTRIAL LOCATION

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Interest in the location of manufacturing industries in the United States is as old as the nation. Its concentration in about 400 counties has long been termed the Manufacturing Belt. The industrial districts which constitute the Belt account for a slowly declining proportion of the nation's total manufacturing over the past half century. During these years the gains of the newer, western half of the Belt have not entirely compensated for the decline of the eastern half. Most of the difference is found in the West, South, Central, and Pacific divisions. In general, the changes in the localization of manufacturing have paralleled population changes. The forms which this recentralization of industry have taken are several, including migration, expansion, and true decentralization. The greatest single factor in this recentralization has been the entry of the Federal Government into the planning and implementation of industrial location.

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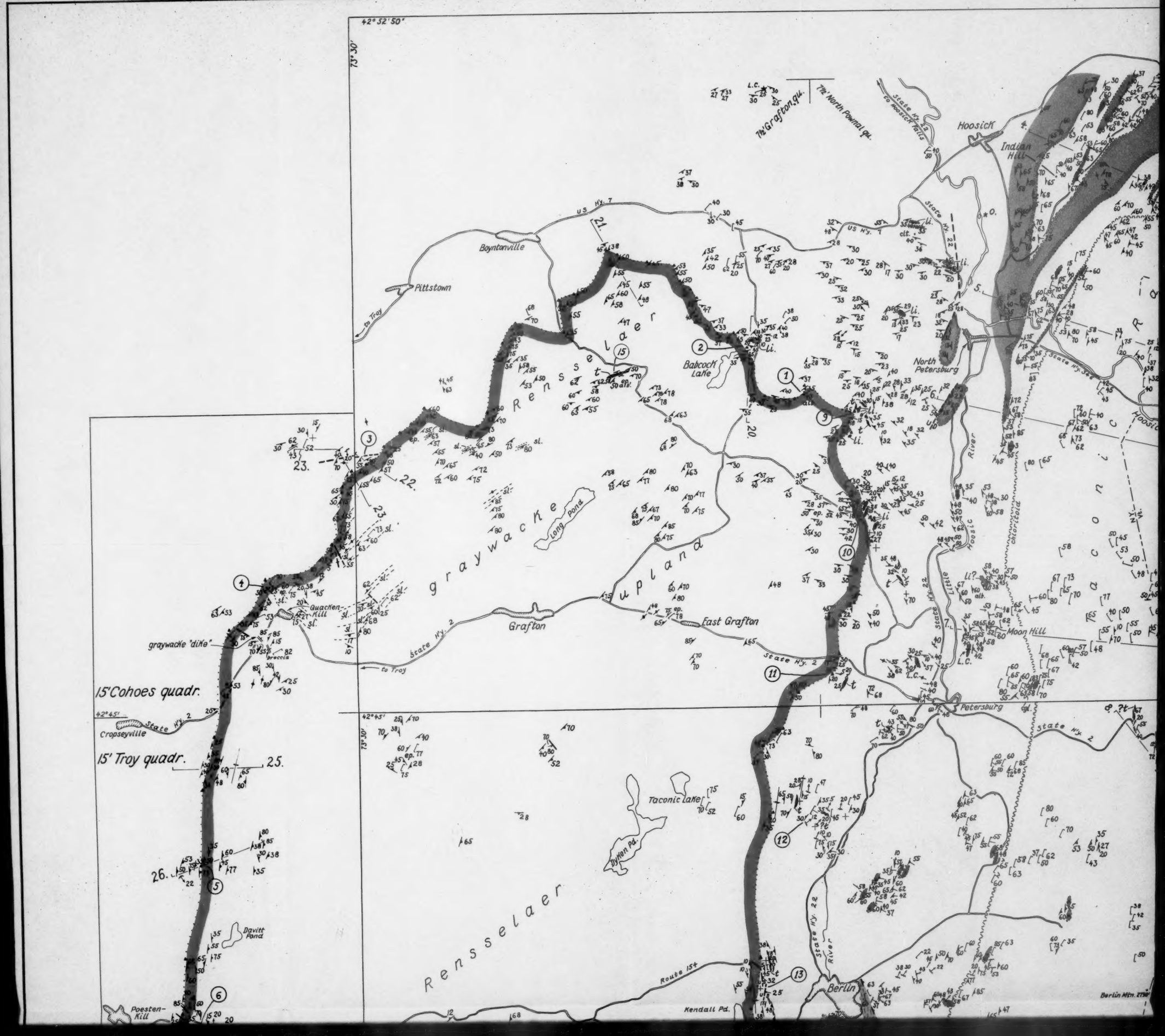

42°52'50"
73°30'
7½' Grafton qu.
7½' North Pownal qu.
State Hy. 22 to Hoosick Falls
Hoosick
Indian Hill
US Hy. 7
Boyntonville
Pittstown
to Troy
State Hy. 22
North Petersburg
Babcock Lake
Rensselaer
graywacke
Long Pond
upland
Grafton
East Grafton
State Hy. 2
to Troy
Guachen Kill
graywacke "dike"
breccia
15' Cohoes quadr.
42°45'
Cropseyville
State Hy. 2
15' Troy quadr.
Moon Hill
Petersburg
State Hy. 2
Taconic Lake
Dyken Pd.
Davitt Pond
Poesten-Kill
Rensselaer
Route 154
State Hy. 22
River
Berlin
Kendall Pd.
Berlin Mtn.
Hoosick
chloritoid
schist
L.C.
Li.
alt.
sl.
ep.
t
23.
22.
26.
25.
20.
21.

Bennington
Southern end of the Limestone valley of western Vermont
Hoosick
Indian Hill
Mt. Anthony
Carpenter Hill
Boyntonville
Babcock Lake
North Petersburg
Hoosic River
North Pownal
Pownal Center
Barber Pond
Mason Hill
Pownal
The Dome
Green Mountains
Moon Hill
Grafton
East Grafton
Long pond
Taconic Lake
Dyken Pd.
Kendall Pd.
Berlin
Petersburg
Berlin Mtn. 2718'
Taconic Range
Rensselaer Plateau
Rensselaer Upland
The Grafton qu.
The North Pownal qu.
North Pownal qu.
Bennington qu.
State Hy. 22 to Hoosick Falls
State Hy. 7
State Hy. 2
State Hy. 22
Route 15t
to Bennington
L.C.
alb.
ep.
sl.
cl.
Vt.
N.Y.
Mass.
42° 45'
North
black phyllitic slate

Explanation:

1 2 3 4 5
6 7 8 9 10
11 12 13 14 15
16 17 18 19 20

graywacke "dike"
Guachen-Kill
Grafton
East Grafton
State Hy. 2
to Troy
graywacke
upland
15' Cohoes quadr.
42°45'
Cropseyville
State Hy. 2
15' Troy quadr.
25.
26.
Davitt Pond
Poesten-Kill
24.
Barberville
Route 154
Taconic Lake
Dyken Pd.
Rensselaer
Petersburg
State Hy. 2
Moon Hill
North Pownal quadr.
N.Y.
Vt.
Mass.
State Hy. 22
Little
L.C.
black phyllitic slate
Berlin Mtn. 2790'
Berlin
Kendall Pd.
Route 154
State Hy. 22
River
Spring Lake
Big Bowman Pd.
Taborton
Taborton quadr.
Sand Lake
Glasshouse
Glass Lake
Crooked Lake
27.
Stephentown Center quadr.
Route 43
State Route 66
North Nassau
28.
Route 43
Stephentown Center
16.
15.
Center Berlin
Cherry plain
Butternut Hill
Eagle Mtn.
Broom
Zone
Slate
Taconic
Range
7½' Berlin quadr.
Hancock quadr.

Explanation:

1. Foliation or bedding dips 20° S-SE.
2. Strike and dip of foliation as in 1, lineation plunges 11° E-SE.
3. Foliation or bedding dips 37° S.-SW., axes of folds plunge 25° W.-SW.
4. Strike and dip of foliation or bedding as before, both lineation and axes of folds plunge 23° E.-SE.
5. Lineation plunges parallel to dip of foliation or bedding
6. Foliation or bedding dips 25° SW., lineation horizontal
7. Foliation or bedding dips 32° SE., axes of folds horizontal
8. Foliation or beds vertical, axes of folds plunge 20° NE.
9. Foliation or bedding as before, with two lineations plunging 30° and 24°, respectively
10. General strike and dip of contorted beds
11. Same as 10, with trend and plunge of axes of folds
12. Same as 10 and 11, both axes of folds and lineation trend NE.-SW., and plunge 47° NE.
13. Horizontal beds or foliation
14. Same as 13, with lineation trending NW.-SE.
15. Horizontal beds or foliation, axes of folds trend N.-NW.-S.-SE.
16. Horizontal beds or foliation, both lineation and axes of folds trend E.-W.
17. Strike and dip of foliation or schistosity in Precambrian rocks
18. Same as 17, lineation plunges 44° E.-SE.
19. Horizontal lineation
20. Lineation plunges E.-SE.
21. Horizontal axes of folds
22. Axes of folds plunge 35° NE.
23. Both lineation and axes of folds plunge 12° E.-SE.

North Nassau
28.
17
State Route 66
Hoags Corners
Curtis Mtn.
Tackawasick Lake
30.
8
7
Route 43
16.
15.
Stephentown Center
731
Stephentown
Kinderhook Creek
State Hy. 22
Black Slate
N.Y. Mass.
Hancock
Route 22
to Williamstown
Potter Mtn.
North
Scale
0 ½ 1 miles 2 3 4
42°
17.
18.
19.
16
dikes of albite-basalt
Taplin Pd.
29.
East Nassau
to Albany
15' Troy quadr.
42° 30'
18
15' Kinderhook qu.
Kinderhook Creek
US Hy. 20
Brainard
State Route 66
alb
Ashley Hill
23
22
19
L.C.
Riders Mills
21
20
Old Chatham
East Chatham
Rock City School
New Concord
Western border of 7½' Canaan quadr.

NW SE West Br.
15. black slate

NNW SSE Black R.
16.

NNW SSE 1633' alb-bas.
17.

NNW 1660' SSE alb-bas. Taplin Pd. list.?
18.

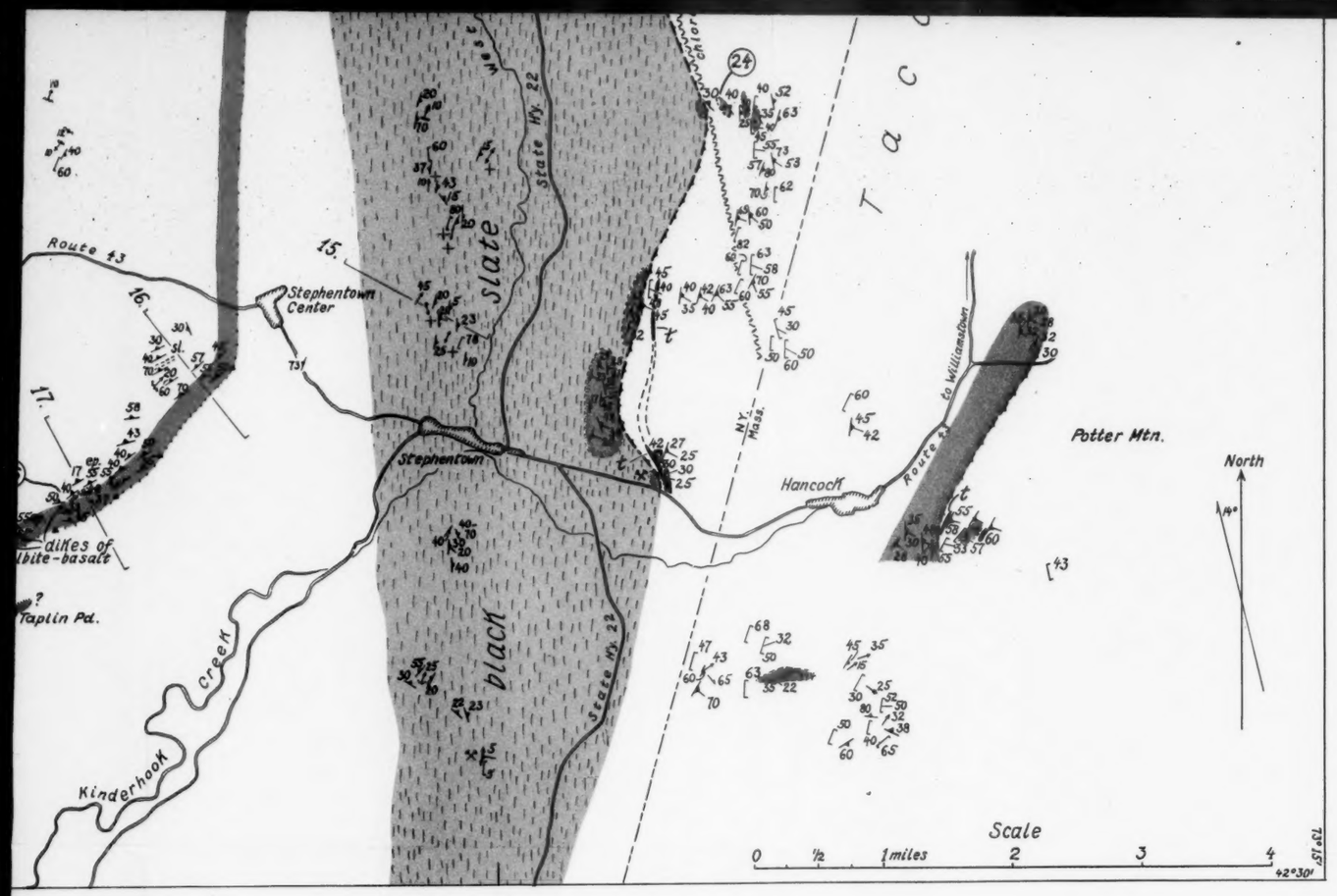
NNW 1420' SSE, N S Bald Hill list.?
19.

Southeastern border of Rensselaer gray-wacke area

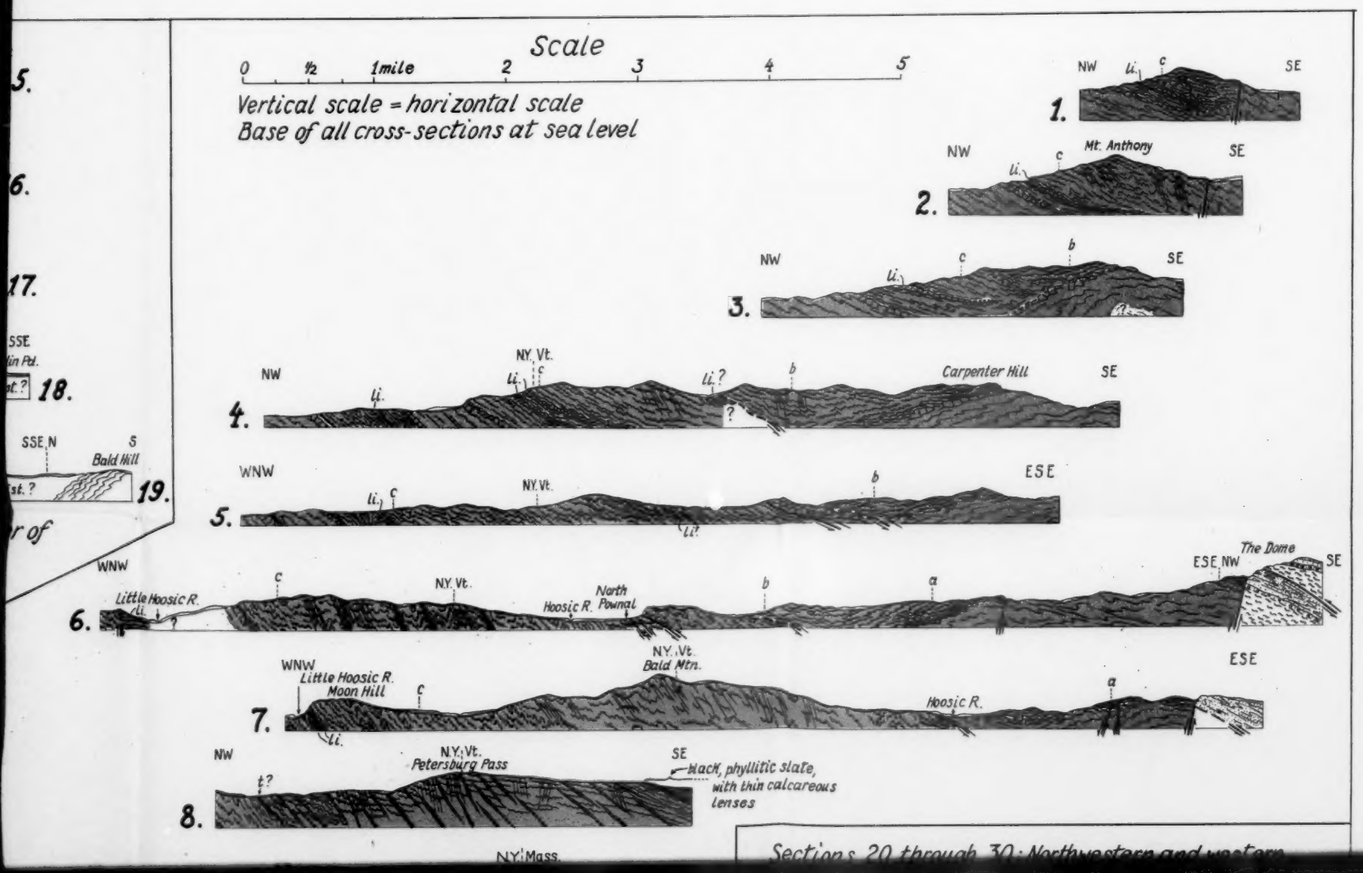
Scale
0 ½ 1mile 2 3 4 5
Vertical scale = horizontal scale
Base of all cross-sections at sea level

1. NW Li. c SE
2. NW Li. c Mt. Anthony SE
3. NW Li. c b SE
4. NW Li. NY. Vt. c Li.? b Carpenter Hill SE
5. WNW Li. c NY. Vt. b ESE
6. WNW Little Hoosic R. Li. c NY. Vt. North Hoosic R. Pownal b a ESE, NW The Dome
7. WNW Little Hoosic R. Moon Hill Li. c NY. Vt. Bald Mtn. Hoosic R. a ESE
8. NW t? NY. Vt. Petersburg Pass SE black, phyllitic slate, with thin calcareous lenses

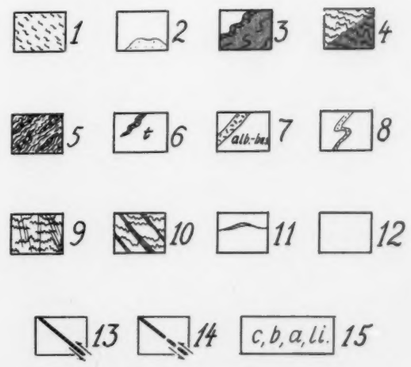
Sections 20 through 30: Northwestern and western



2. Strike and dip of foliation as in 1, lineation plunges 11° E-SE.
3. Foliation or bedding dips 37° S.-SW., axes of folds plunge 25° W.-SW.
4. Strike and dip of foliation or bedding as before, both lineation and axes of folds plunge 23° E.-SE.
5. Lineation plunges parallel to dip of foliation or bedding
6. Foliation or bedding dips 25° SW., lineation horizontal
7. Foliation or bedding dips 32° SE., axes of folds horizontal
8. Foliation or beds vertical, axes of folds plunge 20° NE.
9. Foliation or bedding as before, with two lineations plunging 30° and 24°, respectively
10. General strike and dip of contorted beds
11. Same as 10, with trend and plunge of axes of folds
12. Same as 10 and 11, both axes of folds and lineation trend NE.-SW., and plunge 47° NE.
13. Horizontal beds or foliation
14. Same as 13, with lineation trending NW.-SE.
15. Horizontal beds or foliation, axes of folds trend N.-NW.-S.-SE.
16. Horizontal beds or foliation, both lineation and axes of folds trend E.-W.
17. Strike and dip of foliation or schistosity in Precambrian rocks
18. Same as 17, lineation plunges 44° E.-SE.
19. Horizontal lineation
20. Lineation plunges E.-SE.
21. Horizontal axes of folds
22. Axes of folds plunge 35° NE.
23. Both lineation and axes of folds plunge 12° E.-SE.
24. Slip cleavage, flow cleavage, fracture cleavage, slip planes of small displacements, or s planes of unknown origin dip 72° E.-SE.
25. Same as 24, vertical dip
26. Same planes as in 24, lineation on them plunges 48° E.
27. Same planes as in 24, lineation plunges parallel to dip of planes
28. Strike of anticlinal axis
29. Strike of synclinal axis
30. Fault plane or fault zone, with dip angle where obtainable; dashed where mapped or inferred; where relative movement known, U indicates upthrown block, D downthrown block
31. Vertical fault
32. Fault with trend and plunge of striae
33. Overthrust, with dip angle; dashed where mapped or inferred
34. Formation contact; solid line where exposed or mapped accurately; dash line where inferred
35. Boundary of area underlain by graywacke; triangles mark outcrops
36. Westernmost occurrence (isograd) of chloritoid
37. Biotite isograd
38. Albite isograd
39. Precambrian gneiss complex, undifferentiated
40. Lower Cambrian Cheshire quartzite
41. Cambro-Ordovician limestone and dolomite, contacts indicated by stippling, dots on the limestone side. Narrow zones of limestone are completely stippled
42. Argillaceous sedimentary rocks, including slate, phyllite, and quartz-chlorite schist, with interbeds of siltstone, argillaceous sandstone, and cherty or graphitic lenses. Gray and black slate in Indian Hill district, black slate in Berlin valley
43. Lenses of tuff, or tuffaceous slate; question mark indicates doubtfully tuffaceous rocks
44. Lens of graywacke
45. Lens of quartzite
46. Lens of conglomerate; circles indicate coarse conglomerate in graywacke
47. Phyllitic slate with albite porphyroblasts
48. Quarry
49. Fossil locality; L.C. = Lower Cambrian, O = Ordovician
50. li: limestone lens, question mark if rock may not be in place; sl.: slate zone, mostly in graywacke areas; cqp.: chloritic schist, at Butternut Hill; clt.: chloritoid-bearing slate; ep.: epidote veins; alb.: albite in epidote veins, quartz veins, or associated with metavolcanic rocks
51. Location of topographic quadrangle maps: 1: 15′ Bennington, Vt., 2: 7½′ North Pownal, N. Y.-Vt., 3: 7½′ Grafton, N. Y., 4: 15′ Cohoes, N. Y., 5: 15′ Troy, N. Y., 6: 7½′ Taborton, N. Y., 7: 7½′ Berlin, N. Y.-Mass.-Vt., 8: 7½′ Stephentown Center, N. Y., 9: 7½′ Hancock, Mass.-N. Y., 10: 15′ Kinderhook, N. Y., 12: 7½′ Canaan, N. Y.-Mass., 13: 7½′ State Line, N. Y.-Mass.
52. Number of locality discussed in report

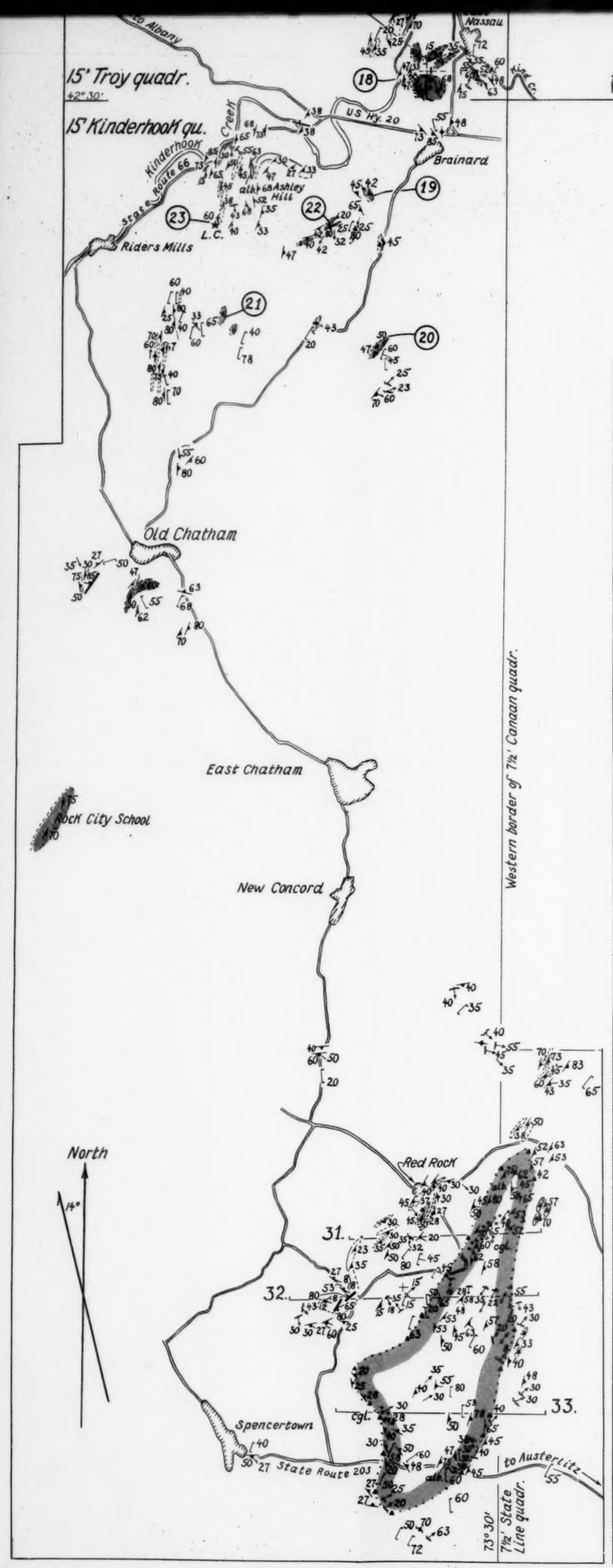


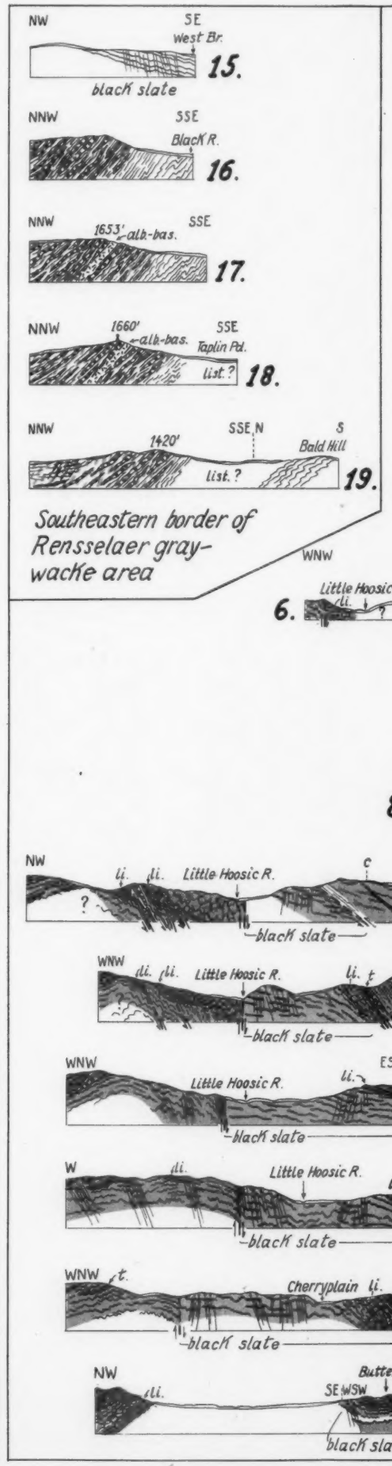
Explanation:

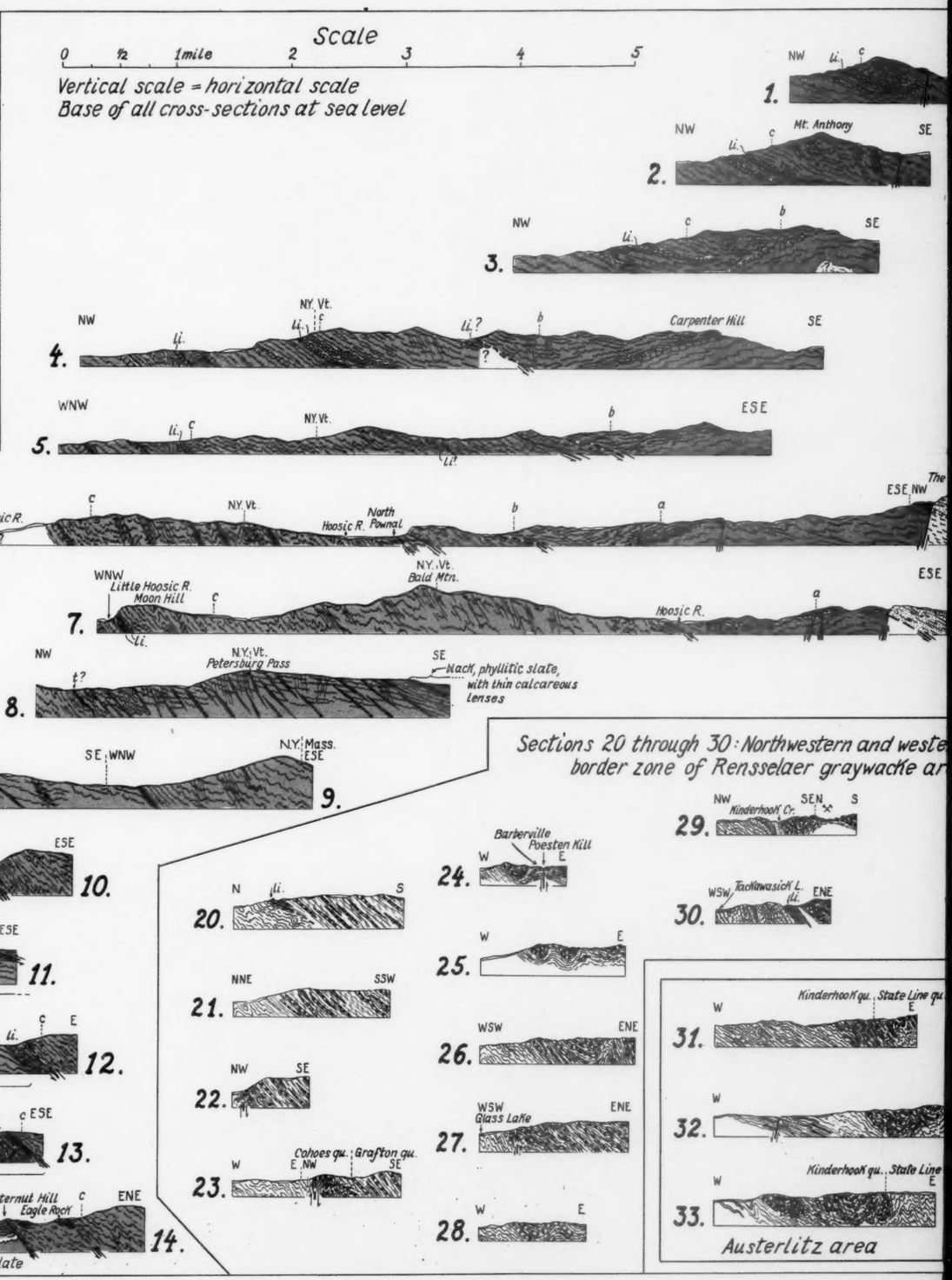


1. Precambrian gneiss complex, undifferentiated
2. Lower Cambrian Cheshire quartzite
3. Cambro-Ordovician limestone and dolomite; thin beds, and contacts of thick zones with other rocks shown by cross bars between beds
4. Argillaceous rocks, including greenishgray, purple, and black slate, quartz-chlorite schist, and siltstone zones
5. Graywacke lenses, interbedded in argillaceous rocks
6. Lens of tuffaceous rocks
7. Albite basalt
8. Quartzite lens in argillaceous rocks
9. Slip cleavage, or fracture cleavage, crosscutting beds
10. Shear zones cutting folded beds
11. Quaternary cover over bedrock
12. Structure of bedrock uncertain
13. Fault, observed or mapped; arrows show relative direction of movement
14. Fault, inferred
15. Isograds of chloritoid (c), biotite (b), and albite (a); thin zones of limestone, or dolomite (li.)

Sections 20 through 30: Northwestern and western




15. NW SE West Br. black slate
16. NNW SSE Black R.
17. NNW 1653' alk-bas. SSE
18. NNW 1660' alk-bas. Taplin Pd. SSE list.?
19. NNW 1420' SSE N S Bald Hill list.?
Southeastern border of Rensselaer graywacke area


Scale
0 ½ 1 miles 2 3 4 5
Vertical scale = horizontal scale
Base of all cross-sections at sea level
1. NW SE
2. NW Mt. Anthony SE
3. NW SE
4. NW NY. Vt. Carpenter Hill SE
5. WNW NY. Vt. ESE
6. WNW Little Hoosic R. NY. Vt. North Hoosic R. Powmal ESE NW The
7. WNW Little Hoosic R. Moon Hill NY. Vt. Bald Mtn. Hoosic R. ESE
8. NW NY. Vt. Petersburg Pass SE black, phyllitic slate, with thin calcareous lenses
9. NW Little Hoosic R. SE WNW NY. Mass. ESE black slate
10. WNW Little Hoosic R. ESE black slate
11. WNW Little Hoosic R. ESE black slate
12. W Little Hoosic R. E black slate
13. WNW Cherryplain E ESE black slate
14. NW SE WSW Butternut Hill Eagle Rock ENE black slate

Sections 20 through 30: Northwestern and weste
border zone of Rensselaer graywacke ar
20. N S
21. NNE SSW
22. NW SE
23. W Cohoes qu. Grafton qu. E NW SE
24. W Barberville Poesten Kill E
25. W E
26. WSW ENE
27. WSW Glass Lake ENE
28. W E
29. NW Kinderhook Cr. SE N S
30. WSW Tackawasick L. ENE
31. W Kinderhook qu. State Line qu. E
32. W
33. W Kinderhook qu. State Line E
Austerlitz area

STRUCTURE MAP AND CROSS SECTIONS OF GRAYWACKE AREAS AND TACONIC RANGE, EAST OF TROY, N

DEP·PUB·LIB

graywacke areas; cqp.: chloritic schist, at Butternut Hill; clt.: chloritoid-bearing slate; ep.: epidote veins; alb.: albite in epidote veins, quartz veins, or associated with metavolcanic rocks
51. Location of topographic quadrangle maps: 1: 15′ Bennington, Vt., 2: 7½′ North Pownal, N. Y.-Vt., 3: 7½′ Grafton, N. Y., 4: 15′ Cohoes, N. Y., 5: 15′ Troy, N. Y., 6: 7½′ Taborton, N. Y., 7: 7½′ Berlin, N. Y.-Mass.-Vt., 8: 7½′ Stephentown Center, N. Y., 9: 7½′ Hancock, Mass.-N. Y., 10: 15′ Kinderhook, N. Y., 12: 7½′ Canaan, N. Y.-Mass., 13: 7½′ State Line, N. Y.-Mass.
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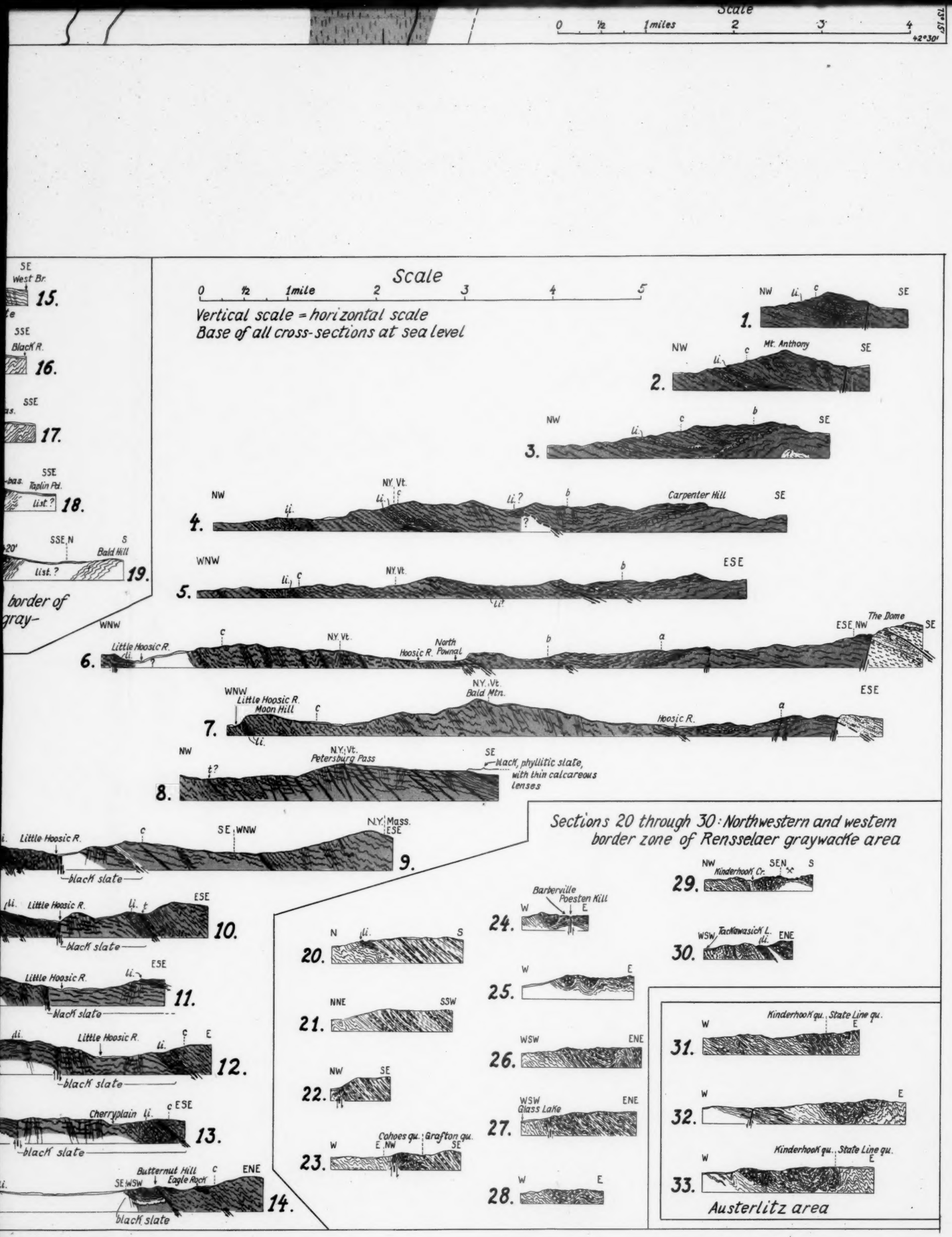
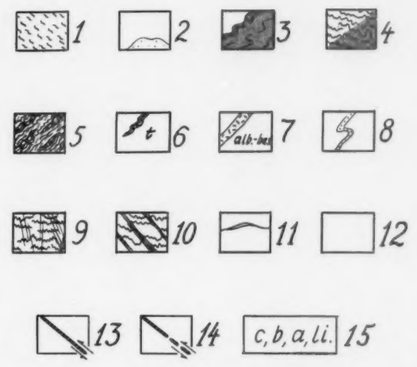

Scale
0 ½ 1 miles 2 3 4 5
Vertical scale = horizontal scale
Base of all cross-sections at sea level
1.
2. Mt. Anthony
3.
4. NY. Vt. Carpenter Hill
5. NY. Vt.
6. Little Hoosic R. NY. Vt. North Hoosic R. Pownal The Dome
7. Little Hoosic R. Moon Hill NY. Vt. Bald Mtn. Hoosic R.
8. NY. Vt. Petersburg Pass black, phyllitic slate, with thin calcareous lenses
9. Little Hoosic R. NY. Mass. black slate
10. Little Hoosic R. black slate
11. Little Hoosic R. black slate
12. Little Hoosic R. black slate
13. Cherryplain black slate
14. Butternut Hill Eagle Rock black slate
15. West Br.
16. Black R.
17.
18. Taplin Pd.
19. Bald Hill
border of gray-
Sections 20 through 30: Northwestern and western border zone of Rensselaer graywacke area
20.
21.
22.
23. Cohoes qu. Grafton qu.
24. Barberville Poesten Kill
25.
26.
27. Glass Lake
28.
29. Kinderhook Cr.
30. Tackawasick L.
31. Kinderhook qu. State Line qu.
32.
33. Kinderhook qu. State Line qu.
Austerlitz area

Explanation:



1. Precambrian gneiss complex, undifferentiated
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3. Cambro-Ordovician limestone and dolomite; thin beds, and contacts of thick zones with other rocks shown by cross bars between beds
4. Argillaceous rocks, including greenishgray, purple, and black slate, quartz-chlorite schist, and siltstone zones
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11. Quaternary cover over bedrock
12. Structure of bedrock uncertain
13. Fault, observed or mapped; arrows show relative direction of movement
14. Fault, inferred
15. Isograds of chloritoid (c), biotite (b), and albite (a); thin zones of limestone, or dolomite (li.)

AND CROSS SECTIONS OF GRAYWACKE AREAS AND TACONIC RANGE, EAST OF TROY, NEW YORK

104°00'
420000 FEET
55'
(Jordan Gap)
50'
103°45'
29°45'
30 000 FEET
40'
35'
Miocene?
Oligocene
Eocene?
Gulf
Comanche
Sun Jacinto Ranch
La Mota
Needle Peak
Rooney Ranch
Wilson Ranch
Wire Gap
Smugglers Gap
Rawls Ranch
Old Ranch
Navajo Creek
Torreon
Alazan Ranch
Alazan Spring
Needle Creek
Middle Creek
Indian Creek
Cienega Creek
Alamito Creek
Mariposa Creek
Marfa and Mexican Railroad
Presidio County Brewster County
Boundary Line
Trail to Seminole
Trail to Marfa and Lajitas
Road to Lajitas
The Dike
Tertiary Igneous Rocks
Tff
Tmmr
Tdt
Tbf
Tsy
Tpt-dt
Tpt
Tb
Quaternary Deposits
Qal
Qg
Trbp
Trb
Trvb
Tra
Trer
Kbp
Kbb
Tff
Tmmr
Tdt
Tbf
Tsy
Tpt-dt
Tpt
Tb
Qal
Qg
Trbp
Trb
Trvb
Tra
Trer
Kbp
Kbb
A
A'
B
B'
BANDERA MESA
GREEN VALLEY
SCALE
VABM X4125
VABM X4135
VABM X4845
BM X4075
BM X4028
BM X4141
BM X4207
BM X4135
BM X4345
BM X3840
BM X3540
BM X3575

EXPLANATION

QUATERNARY

Qal — Alluvium
Recent valley fill and stream alluvium.

Qg — Gravel
High-level and pediment gravels.

UNCONFORMITY

TERTIARY

Miocene? / Oligocene / Eocene? — *Buck Hill volcanic series*

Tra, Trb, Trvb, Trbp — Rawls basalt
Interfingering basalt flows and volcanic breccia. (Trbp) trachybasalt porphyry; (Trb) dense basalt; (Trvb) volcanic basalt breccia; (Tra) trachyandesite.

Ttt — Tascotal formation
Light-colored rhyolitic tuff and sandy tuff in lower part; sandstone, tuffaceous sandstone and conglomerate in upper part; (◦°◦°◦°◦°) massive conglomerate and fresh-water limestone facies in southeastern part of quadrangle.

Tmmr — Mitchell Mesa tuff-flow
Pink to gray rhyolitic tuff-flow

Tdt, Tbf, Tpt — Pruett-Duff tuffs
(Tdt) Duff formation; light-colored rhyolitic tuff with minor conglomerate and fresh-water limestone; (Tbf) intercalated basalt flows in upper part. (Tpt) Pruett formation; light-colored rhyolitic tuff with minor sandstone and conglomerate. Contact uncertain.

UNCONFORMITY

CRETACEOUS

Gulf / Comanche

Kbo — Boquillas formation
Alternating flaggy limestone and shale; calcareous shale predominates in upper part.

Kbu — Buda limestone
Massive, nodular limestone.

Kgs — Grayson clay
Clay-shale with sandy limestone layers.

Kdv — Devils River limestone
Massive limestone with abundant chert nodules.

Kgr — Glen Rose limestone
Massive, dark gray limestone.

INTRUSIVE IGNEOUS ROCKS

Tsy — Syenite
Alkalic microsyenite.

Tg — Gabbro

Topographic base by U. S. Geological Survey

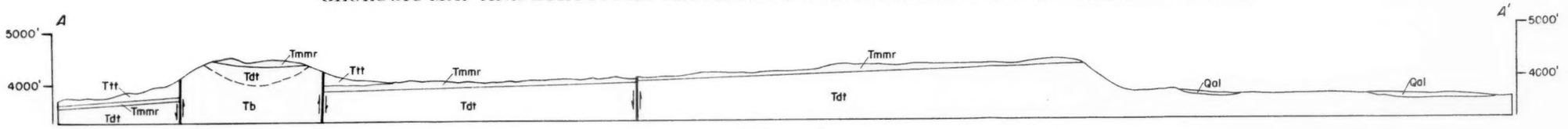
Geology surveyed by R. L. Erickson, 1949 and 1950

Scale 1:62500

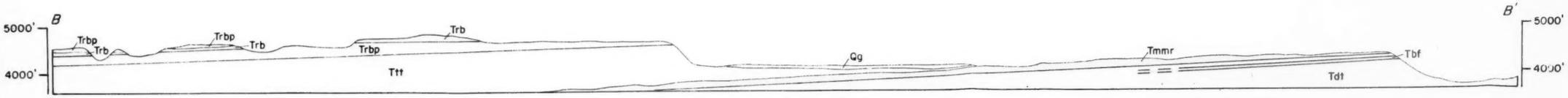
Contour interval 50 feet

Datum is mean sea level

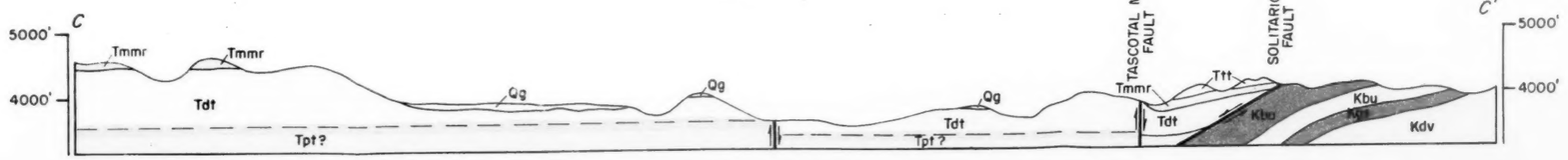
GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS



SECTION *A-A'*



SECTION *B-B'*



SECTION *C-C'*

Scale 1:62500

1 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1000 0 3000 6000 9000 12000 15000 18000 Feet

1 0 1 2 3 4 5 Kilometers

Contour interval 50 feet

Datum is mean sea level

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1917

Geology surveyed by R. L. Erickson, 1949 and 1950

Gulf

Kbo

Boquillas formation

Alternating flaggy limestone and shale; calcareous shale predominates in upper part.

Comanche

Kbu

Buda limestone

Massive, nodular limestone.

Kgs

Grayson clay

Clay-shale with sandy limestone layers.

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Massive, dark gray limestone.

CRETACEOUS

INTRUSIVE IGNEOUS ROCKS

TERTIARY

Tsy

Syenite

Alkalic microsyenite.

Tg

Gabbro

Analcime syenogabbro

Tb

Basalt

Tar

Soda rhyolite

Trsr

Riebeckite soda rhyolite

U / D

Normal fault

U, upthrown side; D, downthrown side; dashed where inferred; dotted where concealed by gravel.

Fault

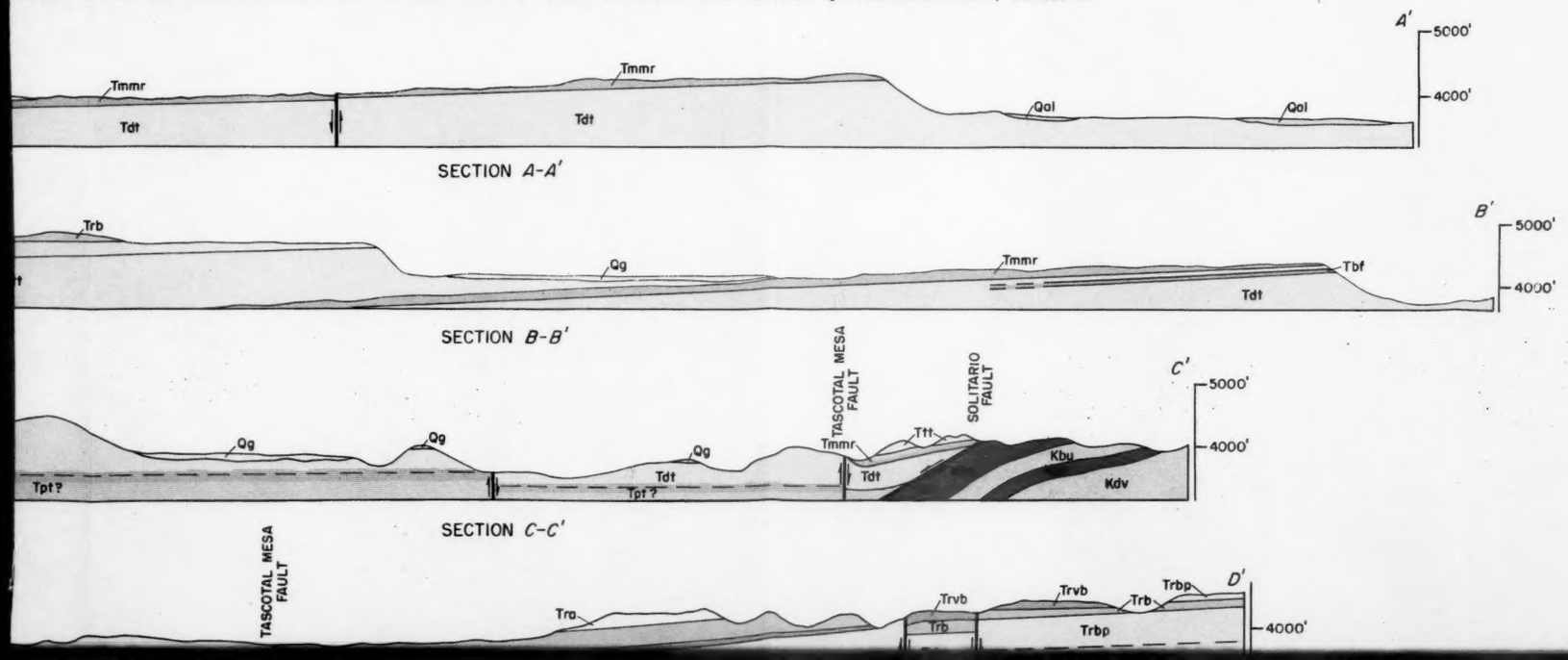
Downthrown side concealed by gravel; position marked by scarp.

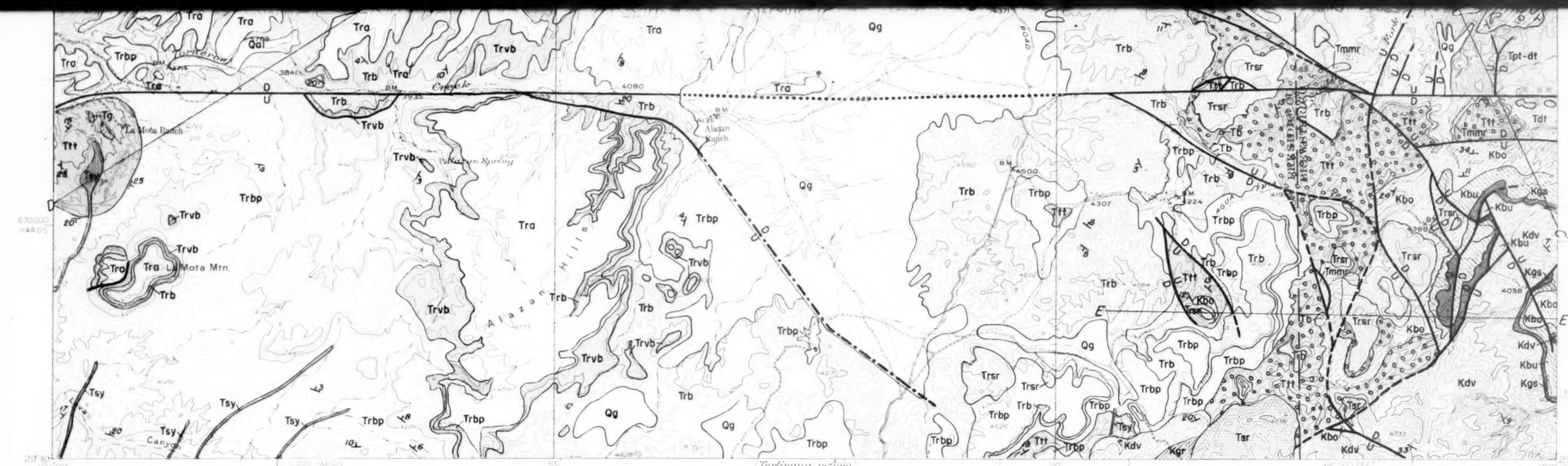
Strike and dip of beds

FL

Fossil locality

LOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS





Topographic base by U S. Geological Survey

Geology surveyed by R L. Erickson, 1949 and 1950

Scale 1/62500

1 Miles

5000 Yards

15000 Feet

5 Kilometers

Contour interval 50 feet

Datum is mean sea level

TERTIARY

Tsy — Syenite

Alkalic microsyenite.

Tg — Gabbro

Anolcime syenogabbro

Tb — Basalt

Tsr — Soda rhyolite

Trsr — Riebeckite soda rhyolite

U / D — Normal fault

U, upthrown side; D, downthrown side; dashed where inferred; dotted where concealed by gravel.

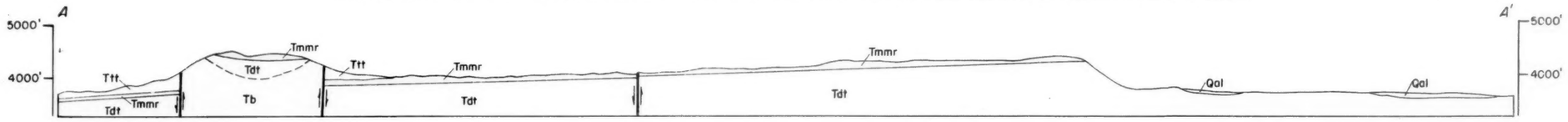
Fault

Downthrown side concealed by gravel; position marked by scarp.

T2 — Strike and dip of beds

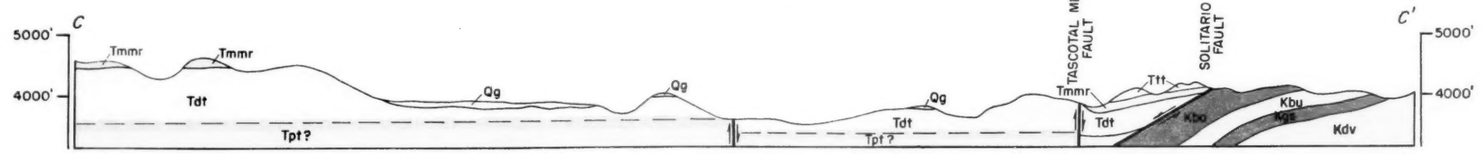
FL — Fossil locality

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS

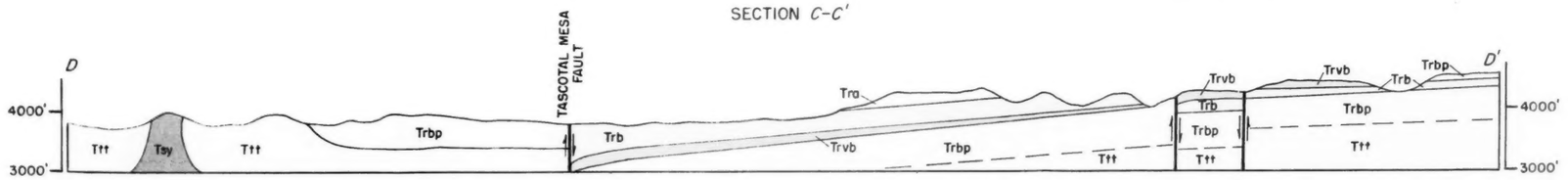


SECTION *A-A'*

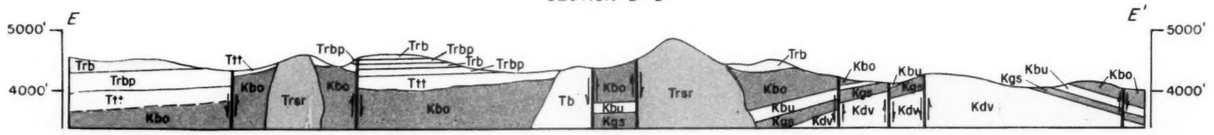
SECTION *B-B'*



SECTION *C-C'*



SECTION *D-D'*

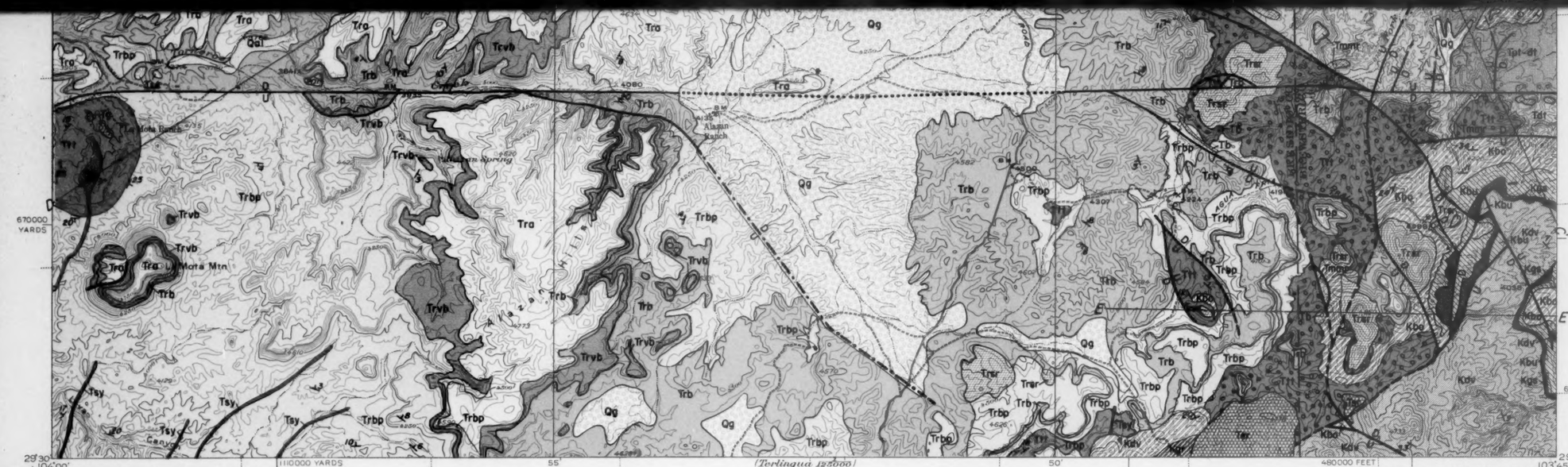


SECTION *E-E'*

DET·PUB·LIB

1000 0 5000 10,000 FEET

Scale of sections



Topographic base by U. S. Geological Survey

Geology surveyed by R. L. Erickson, 1949 and 1950

Scale 1:62500

4 Miles

7000 Yards

18000 Feet

5 Kilometers

Contour interval 50 feet

Datum is mean sea level

APPROXIMATE MEAN DECLINATION, 1917

TRUE NORTH

MAGNETIC NORTH

Tgy Syenite

Alkalic microsyenite.

Tg Gabbro

Analcime syenogabbro

Tb Basalt

Tsc Soda rhyolite

Trsr Riebeckite soda rhyolite

U / D Normal fault

U, *upthrown side*; D, *downthrown side*; *dashed where inferred*; *dotted where concealed by gravel.*

Fault

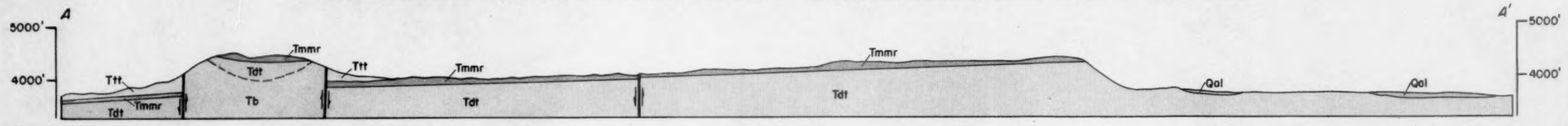
Downthrown side concealed by gravel; position marked by scarp.

T2 Strike and dip of beds

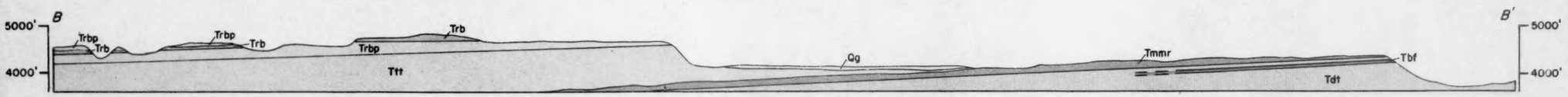
FL Fossil locality

TERTIARY

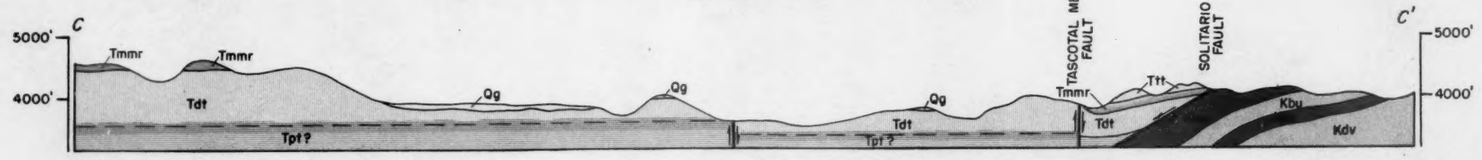
GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE TASTOCAL MESA QUADRANGLE, TEXAS



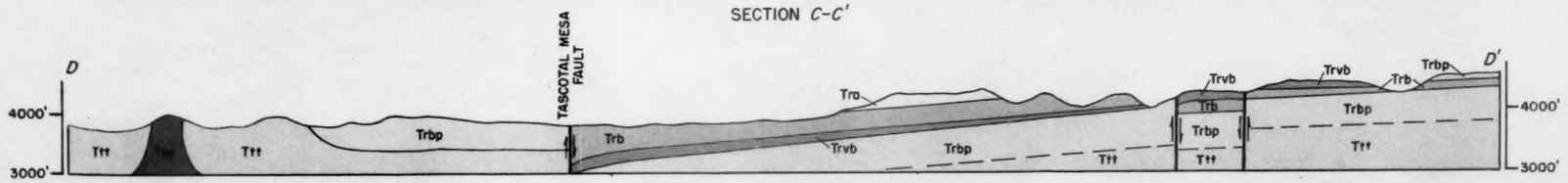
SECTION *A-A'*



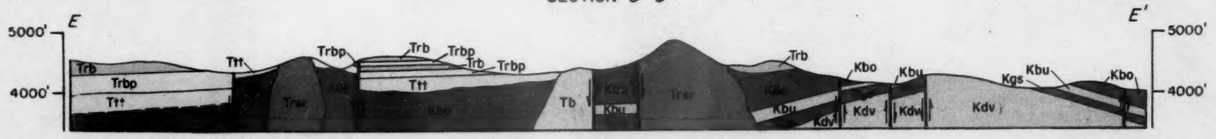
SECTION *B-B'*



SECTION *C-C'*



SECTION *D-D'*



SECTION *E-E'*

1000 0 5000 10,000 FEET

Scale of sections

DET·PUB·LIB

Chart 8d. - CORRELATION OF THE JU

By H

Series	European Stages (Arkell, 1946)	English Formations (Arkell, 1933)	Northwest Europe Standard Zones (Arkell, 1946)	Kyuquot Sound to Esperanza, Vancouver Island, and Parson Bay Region	Queen Charlotte Islands	Southwest Hope Area	Harrison Lake Area	Ashcroft Area	Tyaughton Lake Area	Whitesail Area	Hudson Bay Mountain, Smithers Area	McConnell, Takla, Manson Creek and Fort Fraser Areas	Groundhog Ar
				1	2	3	4	5	6	7	8	9	10
Overlying beds				Lower Cretaceous (marine)	Lower Cretaceous (marine)		Lower Cretaceous (marine)		Lower Cretaceous (upper part of Eldorado Group)		Lower Cretaceous	Lower Cretaceous	Lower Cretaceo
UPPER JURASSIC	Portlandian	Purbeck beds											
		Portland beds	Titanites giganteus	Aucella ex gr. rugosa — Division B — Upper shale member									
			Karbarites okusensis	Phylloceras ex gr. subplicatum — Sandstone siltstone m.									
			Glaucolithites gorei	Aucella ex gr. russiensis — Lower shale member									
			Zaraiskites albani	?									
	Kimmeridgian	Kimmeridge clay	Pavlovia pallasioides				(Not identified)	(Not identified)	Aucella ex gr. mosquensis	(Not identified)			
			Pavlovia rotunda										
			Pectinatites pectinatus										
			Subplanites wheatleyensis										
			Subplanites sp.										
			Gravesia gigas	Aucella ex gr. kirghisensis — Upper shale member					Lower part of Eldorado group				
			Gravesia gravesiana	Aucella bronni									
			Autacosphinctes autissiodorensis	Phylloceras ex gr. gleneense									
			Rasenia mutabilis										
			Rasenia cymodoce										
			Pictonia baylei										
	Oxfordian	Corallian beds	Ringsteadia pseudocordata				?	?	?	?	?		
			Decipia decipiens				Agassiz group	Cornwall formation					
			Perisphinctes cartieri ex.	Aucella bronni var. loguminosa, Aucella bronni — Sandstone member			Agassiz Prairie formation		Card. cf. cardiforme, Aucella ex gr. bronni			Cardioceras aff. praecordatum, C. aff. scarburgense, Perisphinctes	
			Perisphinctes plicatilis				Cardioceras	?	?				
			Cardioceras cordatum	Card. ex gr. lilloettense, Aucella ex gr. bronni			?	Kent form.					
			Quenstedtoceras mariae	No index fossils			?	?					
		Oxford clay	Quenstedtoceras lamberti					Billhook fm.					
			Peltoceras athleta										
			Erymnoceras coronatum										
	Callovian		Kosmoceras jason	Cad. ex gr. doroshini — Lower shale member			Lilloettia, Buckmanniceras, Cadoceras, Paracadoceras, Pseudocadoceras, Macrocephalites of "Catacephalites" aspect	Ashcroft formation					
		Kellaway beds	Sigaloceras calloviense										
			Proplanulites koenigi	?	Saymourites — Upper Yakoun beds		Mysterious Creek form.	Minabariet formation	Taylor group	Undivided sediments and volcanics			
		Cornbrash beds	Macrocephalites macrocephalus										
			Clydoniceras discus										
MIDDLE JURASSIC	Bathonian	Great oolite	(not yet determined)		Belemnoids, Brachiopods — Yakoun formation — Tuff and agglomerate			Basque form.					
			Parkinsonia parkinsoni				?	?	?				
			Stephanoceras humphriesianum		Stephanoceras, Teloceras, Zemistephanus, Kanastephanus, Itinasites, Defonticeras — Lower Yakoun beds			Kallistephanus, Fontanosia — Thompson group — Opuntia form.		Stephanoceras			
	Bajocian	Inferior oolite	Otoites sauzei				(Probably represented by volcanics)	?	Dark gray argilloceous shale				
			Sonninia sowerbyi					Nilakapamux fm.					
			Ludwigia murchisonae					?	?	Tmetoceras regleyi	Sonninia, Sonninites, Guhoania — Middle sedimentary div. — Upper volcanic division — Hazelton group		
			Lioceras opalinum					?					
LOWER JURASSIC	Toarcian	Upper Lias	Lytoceras jurense								?		
			Hildoceras bifrons	Harpoceras Fanninoceras	Harpoceras Fanninoceras — Maude formation								
			Harpoceras serpentinum						Harpoceras				
			Dactylioceras tenuicostatum	?	?				?				
		Middle Lias	Peltaspinoceras spinatum	Volcanic tuffs and breccias interbedded with lava flows									
	Pliensbachian		Amaltheus margaritatus										
			Prodactylioceras davoei										
			Tragophylloceras ibex										
			Uptonia jamesoni	?									
	Sinemurian	Lower Lias	Echioceras raricostatum										
			Oxynoticeras oxynotum										
			Asteroceras obtusum	Harbledown form. (only known from Parson Bay Area)									
			Arietites turneri						(Not identified)	(Not identified)			
			Arnioceras semicostatum										
			Coroniceras bucklandi										
			Scamnoceras angulatum	?									
	Hettangian		Psiloceras planorbe										
Underlying beds				Upper Triassic Parson Bay formation	Upper Triassic	Triassic Lower part of Cultus formation?	Triassic Sicilicum Series	Upper Triassic Nicola group	Upper Triassic Tyaughton group	Triassic	Triassic?	Triassic Lower part of Takla group	?
	4	3	4	24, 27, 52, 97	27, 52, 73, 74, 76, 78	29	25, 27	26, 27	19, 38, 52, 83	38	5, 69, 70	7, 8, 64	16

Aucella sp. — Cultus formation or Tamihi group

"Arniotites" vancouverensis — Stephanoceras

Cultus formation or Tamihi group

Upper part of Takla group

Hazelton group

Asteroceras cf. stellare, Agassiceras cf. scipionianum — Arietites beds — Coroniceras bisulcatum, Vermiceras latilobatum, Vermiceras scylla — Scamnoc. cf. acuticostatum — Schlotheimia beds — Psiloceras canadense — Psiloceras beds

Platypleuroceras ex gr. natrix

"Arnioceras"

Witchellia

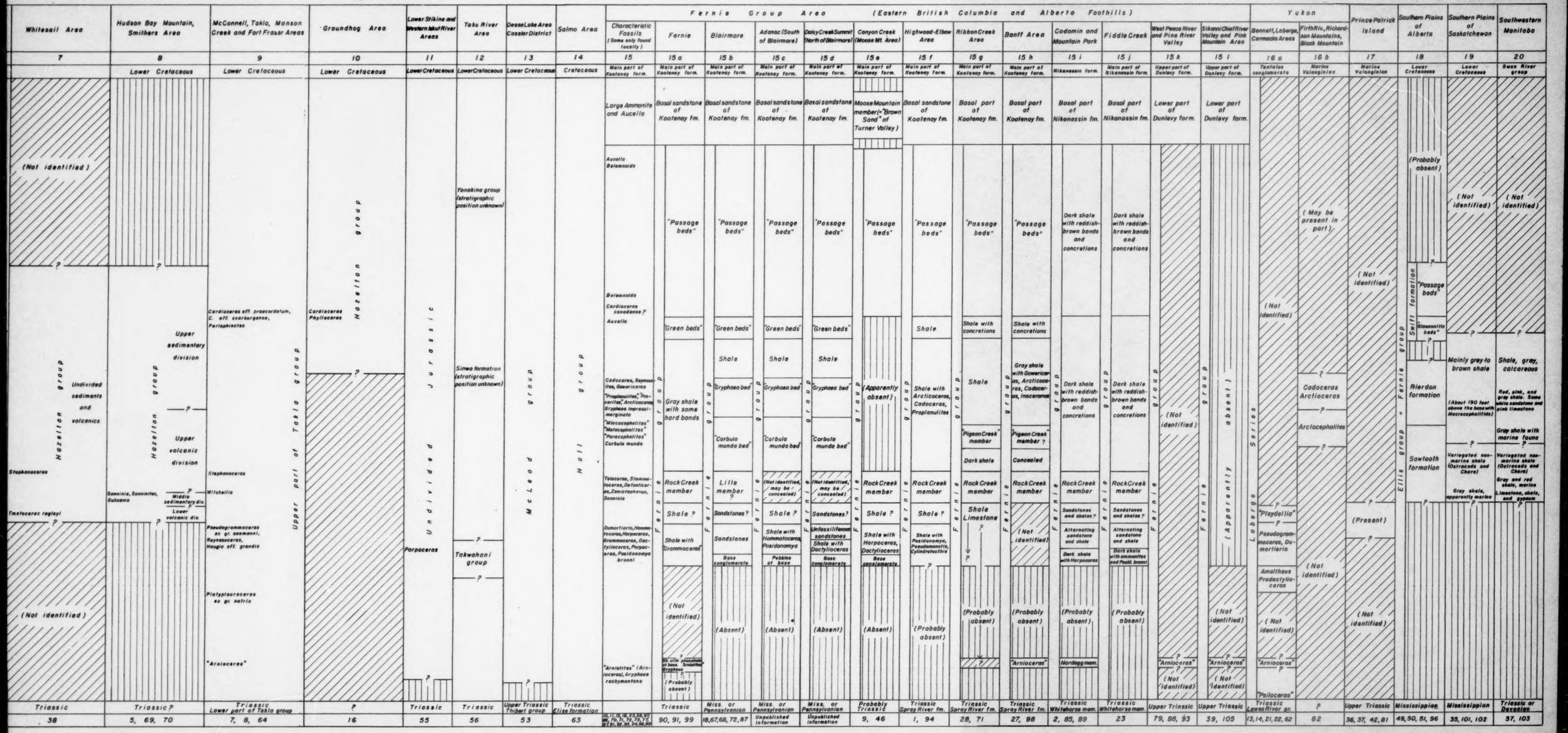
Pseudogrammoceras ex gr. saemanni, Reynesoceras, Hougia aff. grandis

Stephanoceras

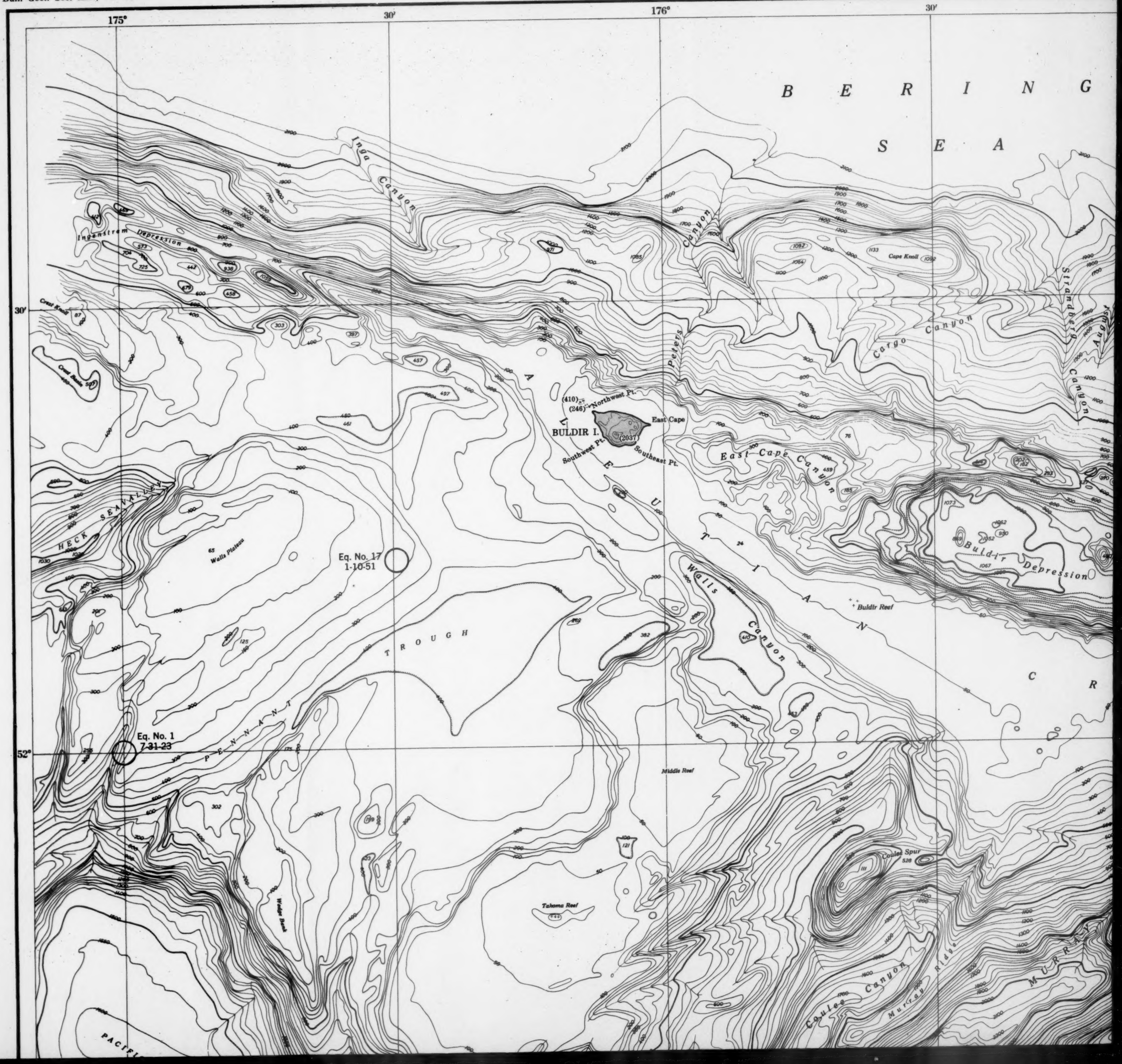
Chart 8d. - CORRELATION OF THE JURASSIC FORMATIONS OF CANADA

By Hans Frebold

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*



Whitesail Area	Hudson Bay Mountain, Smithers Area	McConnell, Takla, Manson Creek and Fort Fraser Areas	Groundhog Area	Lower Stikine and Western Iskut River Areas	Taku River Area	Dease Lake Area Cassiar District	Salmo Area	Characteristic Fossils (Some only found locally)	Fernie	Blairmore	Adanac (South of Blairmore)	Daisy Creek Summit (North of Blairmore)	Canyon Creek (Moose Mt. Area)	Highwood-Elbow Area	Ribbon Creek Area	Banff Area	Cadomin and Mountain Park	Fiddle Creek	West Peace River and Pine River Valley	Sikanni Chief River Valley and Pink Mountain Area	Yukon: Bennett, Laberge, Carmacks Areas	Yukon: Firth Rie., Richardson Mountains, Black Mountain	Prince Patrick Island	Southern Plains of Alberta	Southern Plains of Saskatchewan	Southwestern Manitoba
7	8	9	10	11	12	13	14	15	15a	15b	15c	15d	15e	15f	15g	15h	15i	15j	15k	15l	16a	16b	17	18	19	20
	Lower Cretaceous	Lower Cretaceous	Lower Cretaceous	Lower Cretaceous	Lower Cretaceous	Lower Cretaceous	Cretaceous	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Main part of Kootenay form.	Nikanassin form.	Main part of Nikanassin form.	Upper part of Dunlevy form.	Upper part of Dunlevy form.	Tantalus conglomerate	Marine Valanginian	Marine Valanginian	Lower Cretaceous	Lower Cretaceous	Swan River group
(Not identified)	?	?	?	?	?	?	Hall group	Large Ammonite and Aucella	Basal sandstone of Kootenay fm.	Basal sandstone of Kootenay fm.	Basal sandstone of Kootenay fm.	Basal sandstone of Kootenay fm.	Moose Mountain member (= "Brown Sand" of Turner Valley)	Basal sandstone of Kootenay fm.	Basal part of Kootenay fm.	Basal part of Kootenay fm.	Basal part of Nikanassin fm.	Basal part of Nikanassin fm.	Lower part of Dunlevy form.	Lower part of Dunlevy form.	(Not identified)	(May be present in part)	(Not identified)	(Probably absent)	(Not identified)	(Not identified)
Undivided sediments and volcanics	Upper sedimentary division	Cardioceras cf. cordatum, C. aff. scarburgense, Perisphinctes	Cardioceras Phylloceras	Undivided Jurassic	Yonakina group (stratigraphic position unknown)	McLeod group	Hall group	Aucella Belemnoids	"Passage beds"	"Passage beds"	"Passage beds"	"Passage beds"	"Passage beds"	"Passage beds"	"Passage beds"	"Passage beds"	Dark shale with reddish-brown bands and concretions	Dark shale with reddish-brown bands and concretions	(Not identified)	(Apparently absent)	(Not identified)	(May be present in part)	(Not identified)	"Passage beds"	Mainly gray to brown shale	Shale, gray, calcareous
Hazelton group	Hazelton group	Upper part of Takla group	Hazelton group					Belemnoids																		
								Cardioceras cassidense ? Aucella	"Green beds"	"Green beds"	"Green beds"	"Green beds"		Shale	Shale with concretions	Shale with concretions								Glauconitic beds"		
								Cadoceras, Seymourites, Gowericeras	Gray shale with some hard bands	Shale	Shale	Shale	(Apparently absent)	Shale with Arcticoceras, Cadoceras, Proplanulites	Shale	Gray shale with Gowericeras, Arcticoceras, Cadoceras, Inoceramus	Dark shale with reddish-brown bands and concretions	Dark shale with reddish-brown bands and concretions	(Not identified)	(Apparently absent)	(Not identified)	Cadoceras Arctioceras	(Not identified)	Rierdon formation	Variegated non-marine shale (Ostracods and Chara)
								"Procerites", "Isocerites", Arcticoceras, Gryphaea impressimarginata "Miococephalites" "Metacephalites" "Perocephalites" Corbula munda	Rock Creek member	Lille member ?	Gryphaea bed "Corbula munda bed"	Gryphaea bed "Corbula munda bed"	Rock Creek member	Rock Creek member	"Pigeon Creek" member "Dark shale" Rock Creek member	"Pigeon Creek" member ? Concealed Rock Creek member	Rock Creek member	Rock Creek member			Arctocephalites		(Probably absent)	(Probably absent)
Stephanoceras		Stephanoceras						Tmetoceras, Stemmatoceras, Defonticeras, Zemistephanus, Sonninia	Rock Creek member	Lille member ?	(Not identified, may be concealed)	(Not identified, may be concealed)	Rock Creek member	Rock Creek member	Rock Creek member	Rock Creek member	Rock Creek member	Rock Creek member								
Tmetoceras regleyi	Sonninia, Sowerbyes, Cadomites	Witchellia						Dumortieria, Hammatoceras, Harpoceras, Grammoceras, Dactylioceras, Porpoceras, Pseudogrammoceras broani	Shale ?	Sandstones ?	Shale ?	Sandstones ?	Shale ?	Shale ?	Shale Limestone	Sandstones and shales ?	Sandstones and shales ?			"Pleydellia"					
		Pseudogrammoceras ex gr. saemanni, Reynesoceras, Haugia aff. grandis							Shale with Grammoceras	Sandstones	Shale with Hammatoceras, Posidonomya	Unfossiliferous sandstones Shale with Dactylioceras	Shale with Harpoceras, Dactylioceras	Shale with Posidonomya, Pseudomonotis, Cylindroteuthis	?	Alternating sandstone and shale	Alternating sandstone and shale			Pseudogrammoceras, Dumortieria					
		Platypleuroceras ex gr. satrix							Base conglomerate	Base conglomerate	Pebbles at base	Base conglomerate	Base conglomerate			Dark shale with Harpoceras	Dark shale with ammonites and Posid. bronni								
(Not identified)									(Not identified)	(Absent)	(Absent)	(Absent)	(Absent)	(Probably absent)	(Probably absent)	(Probably absent)	(Probably absent)	(Probably absent)			Amaltheus Prodactylioceras				
		"Arnioceras"		Porpoceras				"Arnioceras" (Arnioceras), Gryphaea rockymontana	Bk. with phosphatic nodules at base. Amaltheus Gryphaea							Nordegg mem.					"Arnioceras"					
									(Probably absent)												(Not identified)					
																					"Psiloceras"					
Triassic	Triassic?	Triassic Lower part of Takla group	?	Triassic	Triassic	Upper Triassic Thibert group	Triassic Elise formation		Triassic	Miss. or Pennsylvanian	Miss. or Pennsylvanian	Miss. or Pennsylvanian	Probably Triassic	Triassic Spray River fm.	Triassic Spray River fm.	Triassic Spray River fm.	Triassic Whitehorse mem.	Triassic Whitehorse mem.	Upper Triassic	Upper Triassic	Triassic Lower Laberge River gr.	?	Upper Triassic	Mississippian	Mississippian	Triassic or Devonian
38	5, 69, 70	7, 8, 64	16	55	56	53	63	10, 11, 16, 18, 83, 88, 92, 99, 110, 71, 72, 73, 74, 91, 97, 98, 104, 105	90, 91, 99	16, 67, 68, 72, 87	Unpublished information	Unpublished information	9, 46	1, 94	28, 71	27, 98	2, 85, 89	23	79, 88, 93	39, 105	13, 14, 21, 22, 62	82	36, 37, 42, 81	49, 50, 51, 96	35, 101, 102	57, 103


175°
30'
176°
30'
30'
52°
B E R I N G
S E A
Inga Canyon
Ingenstrem Depression
Peters Canyon
Cape Knoll
Strandberg Canyon
August Canyon
Cargo Canyon
East Cape Canyon
Buldir Depression
Buldir Reef
BULDIR I.
Northwest Pt.
East Cape
Southwest Pt.
Southeast Pt.
(410)
(246)
(2037)
A
L
E
U
T
I
A
N
C
R
Walls Plateau
Eq. No. 17
1-10-51
TROUGH
Walls Canyon
Eq. No. 1
7-31-23
P E N N A N T
Middle Reef
Tahoma Reef
Coules Spur
Coules Canyon
Murray Ridge
MURRAY
PACIFIC

UNITED STATES
ALEUTIAN ISLANDS - ALASKA
CONFIGURATION OF THE ALEUTIAN RIDGE
PLATE NO. 1, RAT ISLAND GROUP

Contours by W. M. Gibson-Haven Nichols
Contour Interval - 50 fathoms depth
500 feet height
Depths in fathoms below MLLW
Soundings from hydrographic surveys by
U. S. Coast and Geodetic Survey 1934-1952
Shoreline and elevation contours from
U.S.C. & G.S. Chart 8864

30' 177° 30' 178°

BERING SEA

ALEUTIAN CREST

Eq. No. 16
9-16-50

Eq. No. 10
12-12-48

Eq. No. 4
8-21-35

Cargo Canyon
Stalbeth Canyon
August Canyon
Canyon
Segula Canyon
Buldir Depression
Hydro Cone
Buldir Reef
Cape Knoll
Coulee Spur
Coulee Canyon
Murray Ridge
MURRAY SEAVALLEY
Sturgeon Ridge
Bukhti Canyon
Sturdevant Rock
Pillar Rock (119)
Pillar Reef
Pillar Basin
Witchcraft Pt.
Sirius Pt.
Kiska Volcano (4003)
Vulcan Pt.
Haycock Rk.
Sredni Pt.
McArthur Pass
McArthur Reef
Segula Pass
KISKA ISLAND
Kiska Hbr.
Little Kiska I.
Tanadak I.
Tanadak Pass
South Pass
Twin Rks.
Gertrude Cove
Vega Bay
Bukhti Pt.
Cape St. Stephen
Vega Pt.
Sobaka Rk.
Sea Lion Pass
Sea Lion Rk.
Krysi Pass
SEGULA I. (3784)
Volcano
Gula Pt.
Zapad Hd.
Iron Pt.
Chugul Pt.
Khvostof Pass
Khvostof I. (867)
Davidof (1074)
RAT ISLAND

178° 30′ 179° 30′ 180°

30′

52°

Eq. No. 15
9-1-50

Eq. No. 16
9-16-50

Eq. No. 10
12-12-48

Eq. No. 6
3-27-40

Eq. No. 11
8-25-49

Eq. No. 3
2-2-30
4-26-30
5-20-30

Eq. No. 7
7-14-40

Eq. No. 14
7-14-50

Bowie Canyon

Roberts Canyon

Grehell Canyon

Sitkin Canyon

Segula Canyon

Oglala Trough

PETREL BANK

POCHNOI SEAVALLEY

David Swell

Williams Crater

Kay Sea Cone

SEGULA I.
(3784)
Volcano

LITTLE SITKIN I.
Volcano (3921)

Davidof I.
(1074)

Khvostof I.
(867)

SEMISOPOCHNOI ISLAND
(4007)
Caldera
(3024)
(2862)

RAT ISLAND

Gula Pt.
Zapad Hd.
Iron Pt.
Chugul Pt.
Khvostof Pass
Williams Cove
Patterson Pt.
Sitkin Pt.
Pratt Pt.
Prokhoda Pt.
Rat Island Pass
Gunners Cove
Ayugadak Pt.
Bird Cape
Bird Rk.
Tanadak I.
Sea Lion Pass
Sea Lion Rk.
Krysi Pass
McArthur Pass
McArthur Reef
Segula Pass
Tuman Pt.
Pochnoi Pt.
Petrel Pt.
Augustai Hd.

ALEUTIAN CREST

Eq. No. 17
1-10-51

Eq. No. 1
7-31-23

52°

30'

HECK SEAMOUNT

Wells Plateau

PENNANT TROUGH

Wedge Bank

PACIFIC BIGHT

Middle Reef

Tahoma Reef

Wells Canyon

Buldir Reef

Buldir Depression

Hydra Cone

Coulee Spur
526

Coulee Canyon

Murray Ridge

MURRAY SEAVALLEY

Murray Basin
2408

Kiska Ridge

Aleut Dome
2240

Tahoma Basin
2670

Tahoma Swell
2460

Broad Canyon

ALEUTIAN TROUGH

Kiska Knoll
2505

Kiska Basin
2920

ALEUTIAN

Buldir Depression
Hydro Cone
Segula Canyon
Sitkin Canyon
Eq. No. 10
12-12-48
Sturdevant Rock
Pillar Rock (119)
Sirius Pt.
Kiska Volcano (4003)
Vulcan Pt.
Haycock Rk.
McArthur Pass
McArthur Reef
Segula Pass
Gula Pt.
SEGULA I. (3784)
Zapad Hd.
Volcano
Iron Pt.
Chugul Pt.
Khvostof I. (867)
Khvostof Pass
Williams Cove
Patterson Pt.
Davidof I. (1074)
Sitkin Pt.
Volcano (3921)
LITTLE SITKIN I.
Pratt
Prokhoda Pt.
Rat Island Pass
Pillar Reef 17
Pillar Basin 128
Witchcraft Pt.
Srednі Pt.
111
CREST
Eq. No. 4
8-21-39
KISKA ISLAND
Kiska Hbr.
Little Kiska I.
Tanadak I.
Tanadak Pass
South Pass
Twin Rks.
Gertrude Cove
Vega Bay
Bukhti Pt.
Cape St. Stephen
ALEUTIAN
Sea Lion Pass
Sea Lion Rk.
Krysi Pass
Vega Pt.
Sobaka Rk.
MURRAY SEA VALLEY
Stepan Ridge
Bukhti Canyon
RAT ISLAND
Gunners Cove
Ayugadak Pt.
CREST
Oglala Pass
Eq. No. 7
7-14-40
Bird Rk.
Aleut Pt.
Salmi Canyon
Vega Canyon
Sobaka Canyon
Krysi Canyon
Rat Island Canyon
Agadak Canyon
Bird Canyon
Eq. No. 20
7-11-51
MURRAY SEA VALLEY
Kiska Basin
2272
Tack Swell
Dennis Swell
2022
BENCH
Eq. No. 18
1-15-51(2)

Eq. No. 10
12-12-48

Eq. No. 6
3-27-40

Eq. No. 11
8-25-49

Eq. No. 3
2-2-30
4-26-30
5-20-30

Eq. No. 7
7-14-40

Eq. No. 14
7-14-50

Eq. No. 13
6-14-50

Eq. No. 19
5-10-51

Eq. No. 9 & 12
11-22-48
11-28-49

Eq. No. 18
1-15-51(2)

52°

30'

Williams Crater

Sitkin Canyon

PETREL BANK

SEGULA I.
(3784)
Volcano
Zapad Hd.
Gula Pt.
Iron Pt.
Chugul Pt.

Khvostof I.
(867)
Khvostof Pass
Davidof I.
(1074)

Williams Cove
William Cove
Patterson Pt.
Volcano
(3921)
LITTLE SITKIN I.
Sitkin Pt.
Pratt Pt.
Prokhoda Pt.
Rat Island Pass

Kay Sea Cone

Petrel Pt.
Tuman Pt.
(4007)
SEMISOPOCHNOI ISLAND
Caldera
(3024)
(2862)
Pochnot Pt.
Sugarloaf Hd.

Krysi Pass
ANCREST

RAT ISLAND
Gunners Cove
Ayugadak Pt.

Oglala Pass
Bird Cape
Bird Rk.
Aleut Pt.

(1180)
AMCHITKA ISLAND
Chitka Pt.

OGLALA TROUGH

POCHNOI SEAVALLEY

Sunday Basin

ALEUTIAN CREST

Ayugadak Canyon
Bird Canyon
Semisopochnoi Canyon
Makarius Canyon
Ward Canyon

CONSTANTINE HARBOR ARM

Kiriloi Pt.
Constantine Hbr.
Ivakin Pt.
S. Bight
East Cape
St. Makarius Pt.

Ward Basin
Ward Swell

BIGHT

30'

Murray Basin
2460

Kiska Ridge
2370

MURRAY SEA VALLEY

Alrid Dome
2240

Tahoma
2670
Basin

Tahoma Swell
2460

Broad Canyon

ALEUT TROUGH

2715

Kiska Knoll
2505

Kiska
Basin
2990

ALEUTIAN

4005

ALEUTIAN

3385

3305

51°

Eq. No. 5
9-8-39

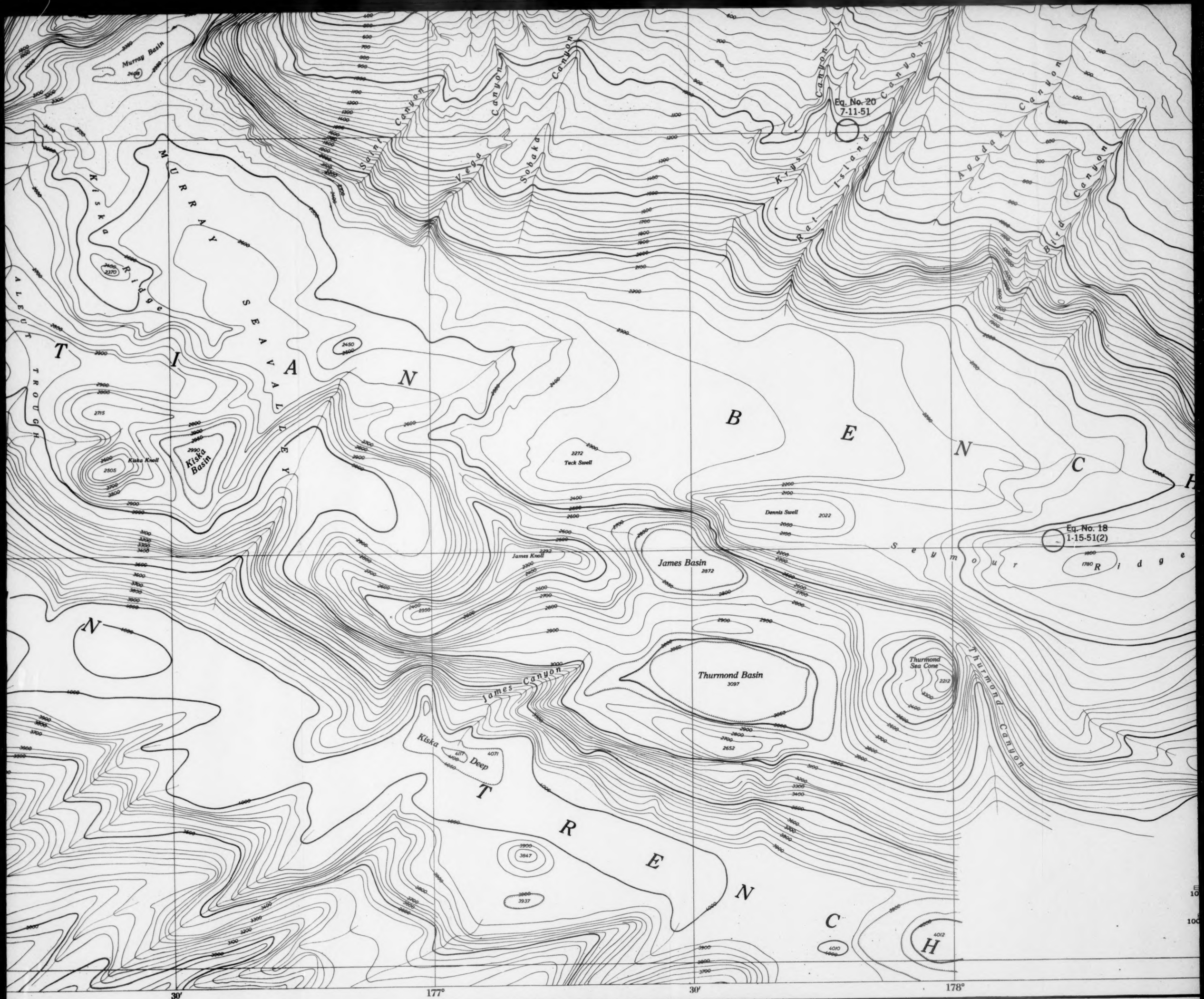
30'

175°

30'

176°

30'



CONFIGURATION OF THE ALEUTIAN RIDGE

Aleut Pt.

(1180)

AMCHITKA ISLAND

Chitka Pt.

Kirtin Pt.

Constantine Hbr.

Ivakin Pt.

S. Bight

East Cape

St. Makarius Pt.

ALEUTIAN CREST

CONSTANTINE ARM

Sunday Basin

Eq. No. 13
6-14-50

30'

Krust Island Canyon

Rat Island Canyon

Eq. No. 20
7-11-51

Aggadak Canyon

Bird Canyon

Seumour Canyon

Major Canyon

Karins Canyon

Ward Canyon

Eq. No. 19
5-10-51

Ward Swell

Ward Basin

Eq. No. 9 & 12
11-22-48
11-28-49

51°

B E N C H

Dennis Swell

Eq. No. 18
1-15-51(2)

Seumour Ridge

Eq. No. 2 & 8
11-15-27
9-9-45

Thurmond Sea Cone

Thurmond Canyon

nd Basin

N C H

NAUTICAL MILES

10 0 10 20 30

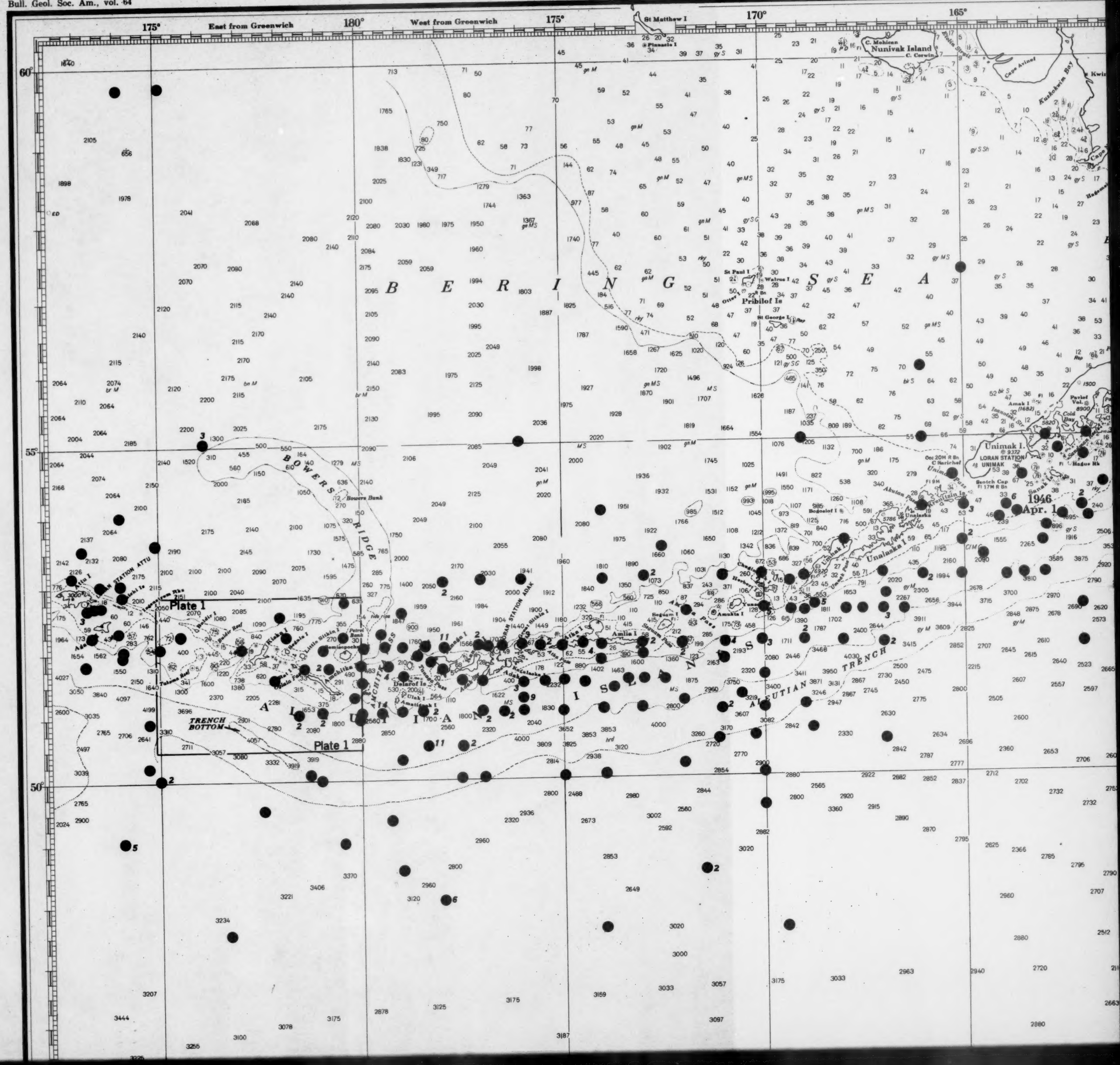
YARDS

10000 0 10000 20000 30000 40000 50000 60000 70000

30'

178° 30' 179° 30' 180°

TIAN RIDGE


175°
East from Greenwich
180°
West from Greenwich
175°
170°
165°
60°
55°
50°
St Matthew I
Pinnacle I
C. Mohican
Nunivak Island
C. Corwin
Cape Avinof
Kuskokwim Bay
Etolin Strait
BERING SEA
St Paul I
Walrus I
Otter I
Pribilof Is
St George I
Unimak I.
LORAN STATION UNIMAK
Scotch Cap Fl 17M R Bn
Unalaska I
Amaknak I
Akutan Pass
Akutan I
Umnak I
Samalga Pass
Bogoslof I
Seguam Pass
Amlia I
Atka I
Kasatochi I
Adak
Kanaga I
Tanaga I
Kiska I
Segula I
Little Sitkin I
Semisopochnoi I
Amchitka I
Petrel Bank
Tanadak I
Ulak I
Amatignak I
Delarof Is
Tanaga Pass
Amchitka Pass
Bowers Bank
BOWERS RIDGE
ALEUTIAN TRENCH
TRENCH BOTTOM
Plate 1
Plate 1
1946
Apr. 1

180° West from Greenwich 175° 170° 165° 160° 155°

60° 55° 50°

St Matthew I

C. Mohican
Nunivak Island
C. Corwin

Etolin Strait

Cape Avinof

Kuzkokwim Bay

Kwinhagak

Cape Newenham

Hagemeister Strait

Togiak

Nushagak Bay

Cape Constantine

Stolin Pt.

Kvichak Bay

Cape Chichagof

Egegik

Mt. Peulik 5000

Ugashik Bay

Cape Greig

BRISTOL BAY

Wide Bay

Mt. Chiginigak 7000

ALASKA PENINSULA

Port Heiden

Chignik Bay

Cape Seniavin

Port Moller

Lighthouse Rks

Chirikof I

Pavlof Vol. 8900

Pavlof Bay

Cold Bay

Amak I (1682)

Isanotski Str.

Shumagin Is

Unimak I. 9372
LORAN STATION UNIMAK

Hague Bk

Scotch Cap Fl 17M R Bn

Fl 19M

Ugamak I

Akutan Pass

Akutan I

Unalaska I

Sanak I

1946 Apr. 1

BERING SEA

St Paul I

Walrus I

Otter I

Pribilof Is

St George I

Bogoslof I

Umnak I

Chuginadak I

Herbert Bay

Amlia I

Segula I

Atka I

Amchitka I

Tanaga I

Kanaga I

Adak

LORAN STATION ADAK

Kiska I

Semisopochnoi I

Rat Is

Delarof Is

Buldir I

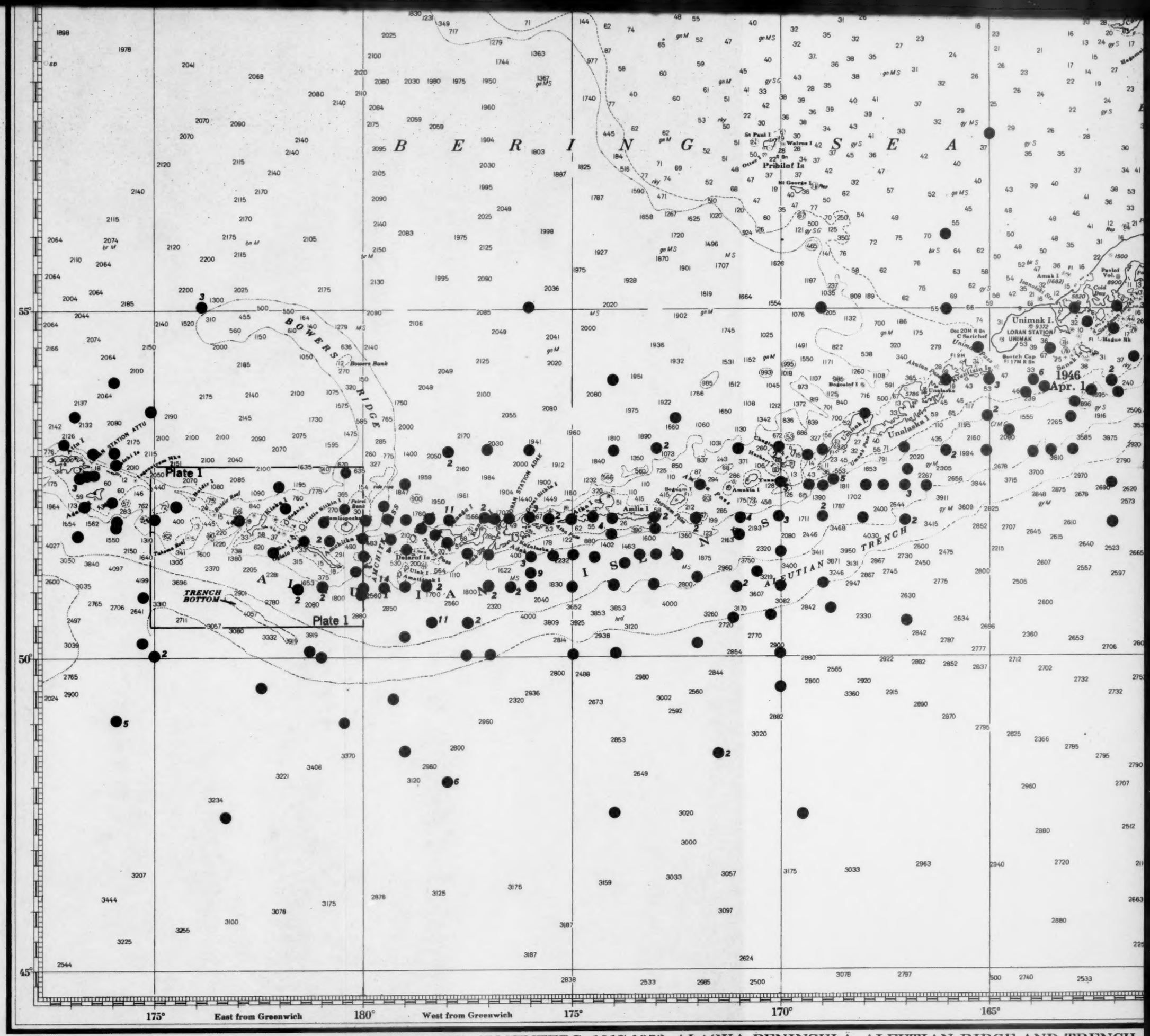
Bowers Bank

BERING SEA BASIN

ALEUTIAN RIDGE

ALEUTIAN TRENCH

ALEUTIAN ISLANDS



EARTHQUAKE EPICENTERS, 1917-1952, ALASKA PENINSULA, ALEUTIAN RIDGE AND TRENCH

Section of U.S.C. & G.S. Chart No. 9000

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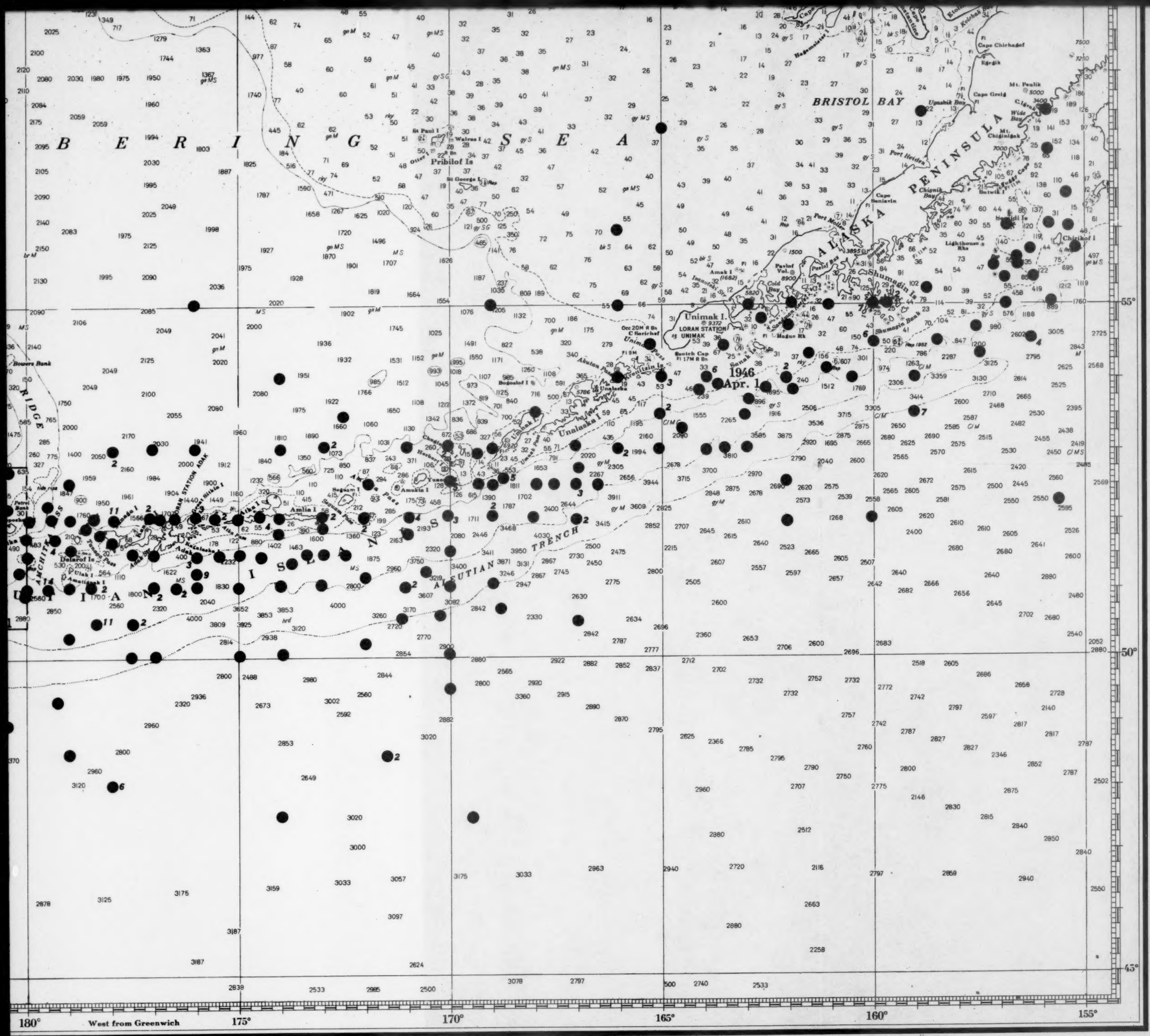
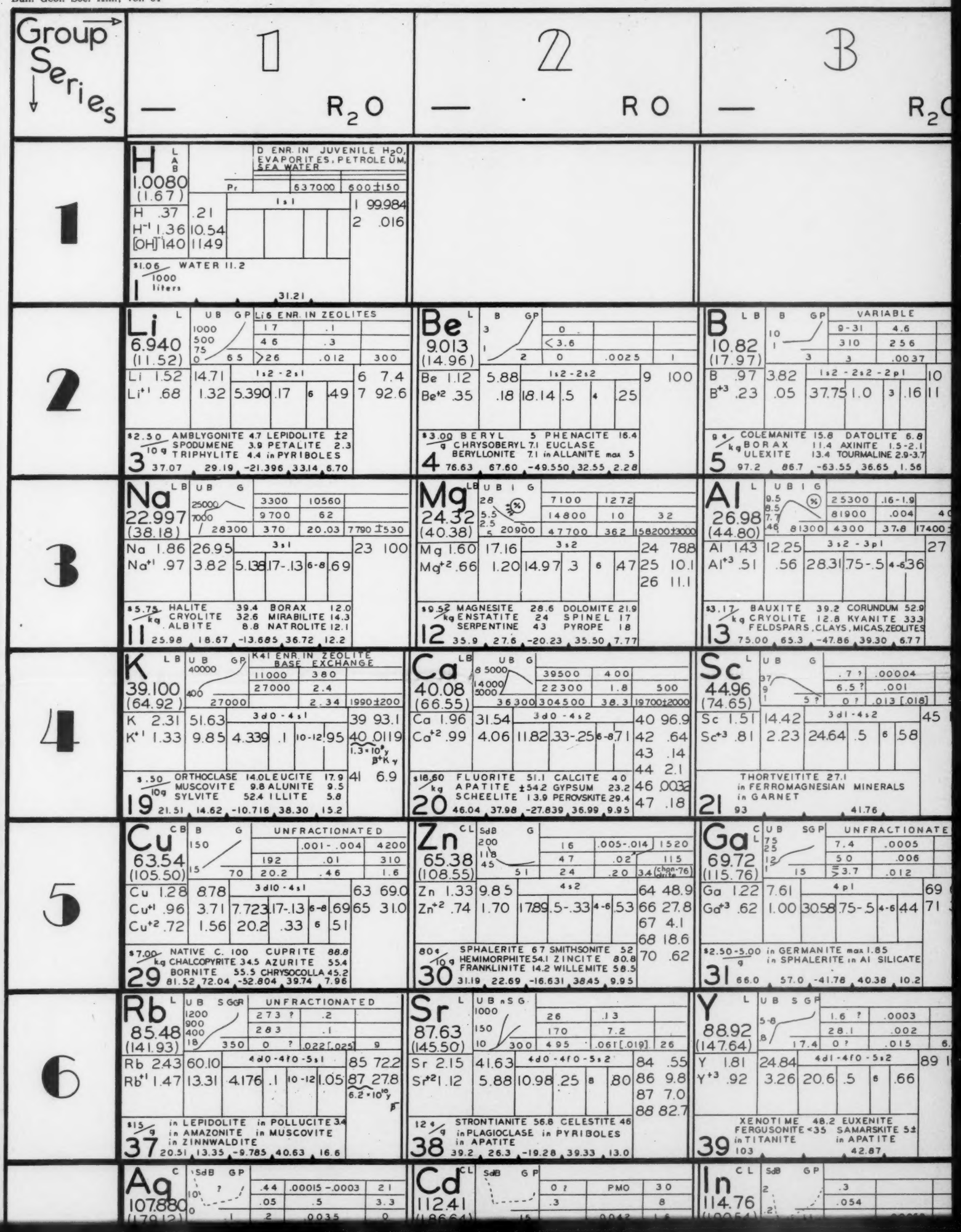


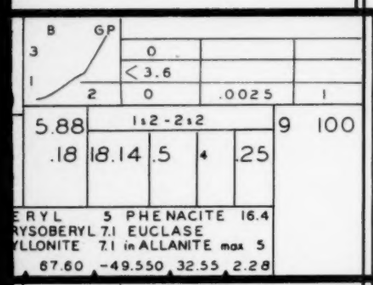
EARTHQUAKE EPICENTERS, 1917-1952, ALASKA PENINSULA, ALEUTIAN RIDGE AND TRENCH

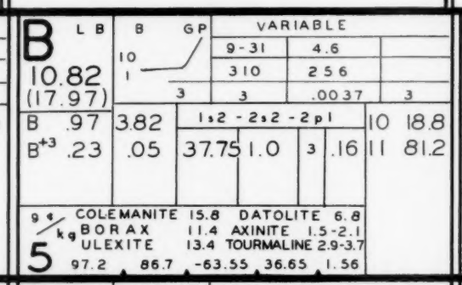
Section of U.S.C. & G.S. Chart No. 9000

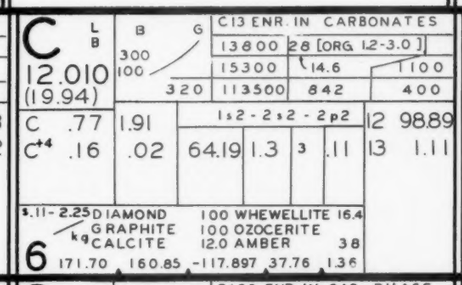
Actinium	Ac	89
Actinium K-francium		
Actinon-isotope of radon[219]		
Alabamine-astatine		
Aldebaranium-ytterbium		
Aluminum	Al	13
Americium	Am	95
Antimony	Sb	51
Argentum-silver		
Argon	A	18
Arsenic	As	33
Astatine	At	85
Aurum-gold		
Austrium-impure gallium		
Barium	Ba	56
Berkelium	Bk	97
Beryllium	Be	4
Bismuth	Bi	83
Boron	B	5
Brevium-isotope of protactinium[234]		
Bromine	Br	35
Cadmium	Cd	48
Calcium	Ca	20
Californium	Cf	98
Carbon	C	6
Cassiopeium-lutecium		
Celtium-lutecium		
Cerium	Ce	58
Cesium	Cs	55
Chlorine	Cl	17
Chromium	Cr	24
Cobalt	Co	27
Columbium-niobium		
Copper	Cu	29
Coronium-hypothetical solar element		
Curium	Cm	96
Cyclonium-promethium		
Demonium-dysprosium		
Deuterium-isotope of hydrogen[2]		
Didymium-neodymium and praseodymium		
Dvitellurium-polonium		
Dwi-manganese-rhenium		
Dysprosium	Dy	66
Eka-aluminum-gallium		
Eka-boron-scandium		
Eka-cesium-francium		
Eka-iodine-astatine		
Eka-manganese-technetium		
Eka-silicon-germanium		
Eka-tantalum-protactinium		
Emanation-radon		
Erbium	Er	68
Erythronium-vanadium		
Europium	Eu	63
Ferrum-iron		
Florentium-promethium		
Fluorine	F	9
Francium	Fr	87
Gadolinium	Gd	64
Gallium	Ga	31
Germanium	Ge	32
Glucin(i)um-beryllium		
Gold	Au	79
Hafnium	Hf	72
Helium	He	2
Holmium	Ho	67
Hydrargyrum-mercury		
Hydrogen	H	1
Illinium-promethium		
Indium	In	49
Iodine	I	53
Ionium-isotope of thorium[230]		
Iridium	Ir	77
Iron	Fe	26
Kalium-potassium		
Krypton	Kr	36
Lanthanum	La	57
Lead	Pb	82
Lithium	Li	3
Lutecium	Lu	71
Magnesium	Mg	12
Manganese	Mn	25
Masurium-technetium		
Mercury	Hg	80
Molybdenum	Mo	42
Natrium-sodium		
Nebulium-hypothetical cosmic element		
Neodymium	Nd	60
Neoytterbium-ytterbium		
Neptunium	Np	93
Neon	Ne	10
Nickel	Ni	28
Niobium	Nb	41
Nilon-radon		
Nitrogen	N	7
Osmium	Os	76
Oxygen	O	8
Palladium	Pd	46
Phosphorus	P	15
Platinum	Pt	78
Plumbum-lead		
Plutonium	Pu	94
Polonium	Po	84
Potassium	K	19
Praseodymium	Pr	59
Promethium	Pm	61
Protactinium	Pa	91
Radium	Ra	88
Radium emanation-radon		
Radium F-polonium		
Radon	Rn	86
Rhenium	Re	75
Rhodium	Rh	45
Rubidium	Rb	37
Ruthenium	Ru	44
Samarium	Sm	62
Scandium	Sc	21
Selenium	Se	34

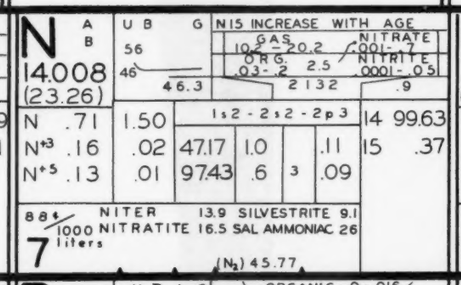


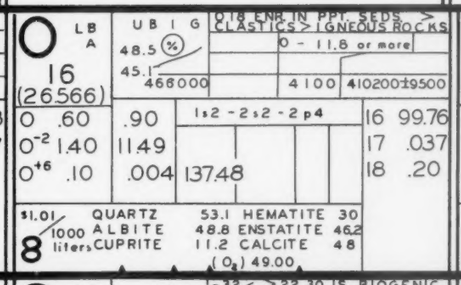
2	3	4	5	6	7
RO	— R_2O_3	RH_4 RO_2	RH_3 R_2O_5	RH_2 RO_3	RH

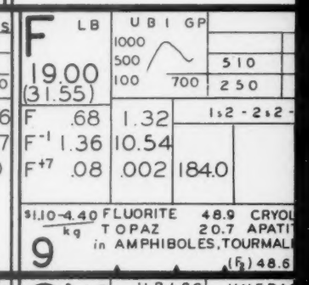


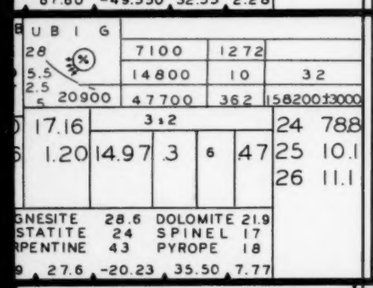


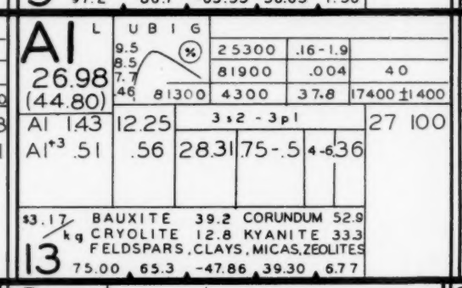


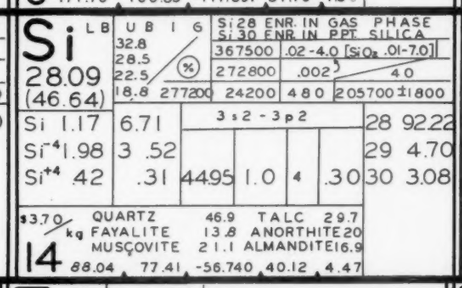


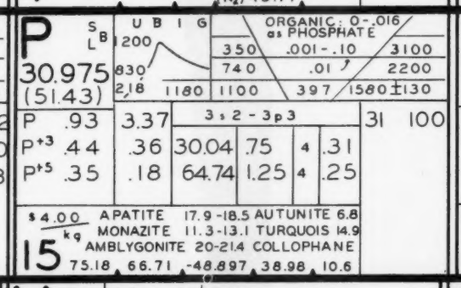


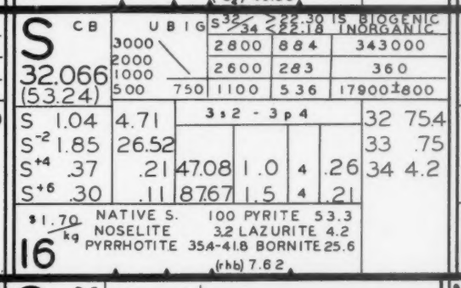


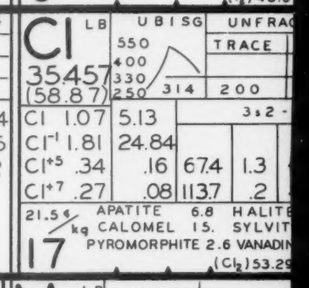


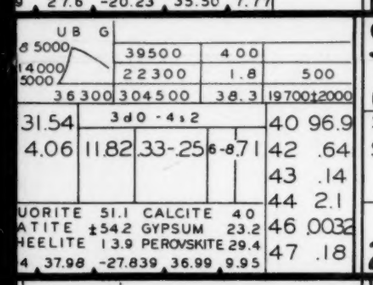


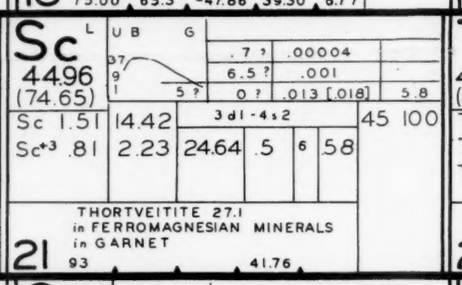


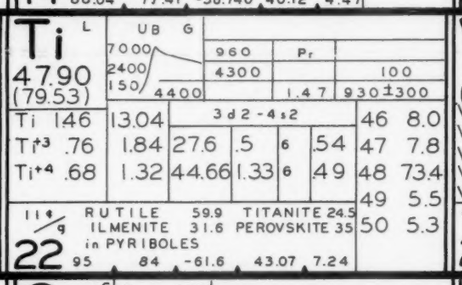


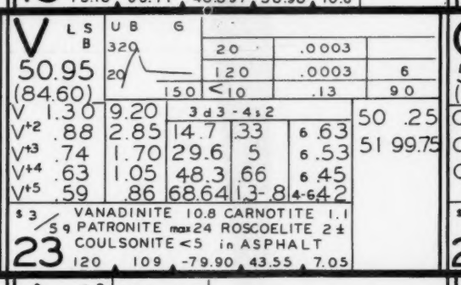


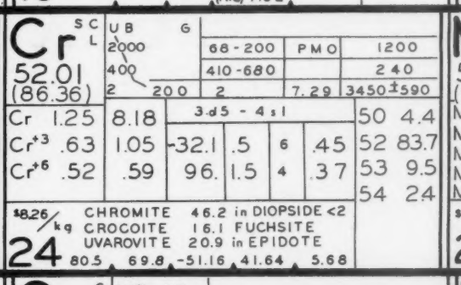


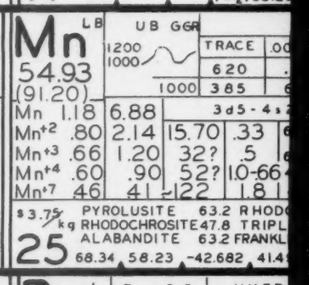


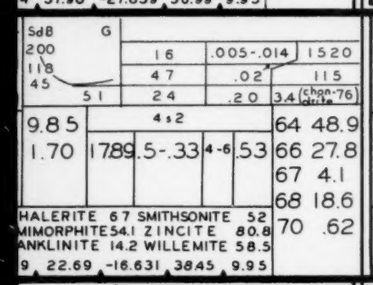


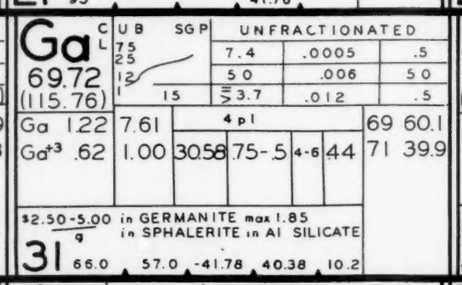


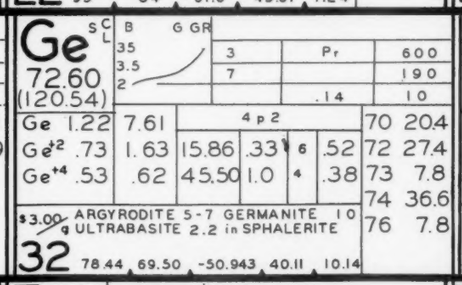


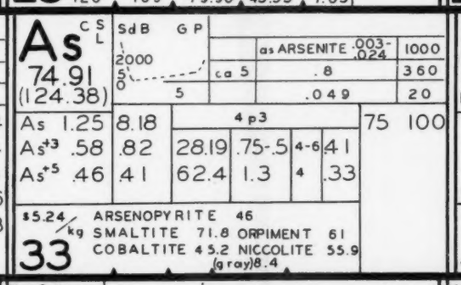


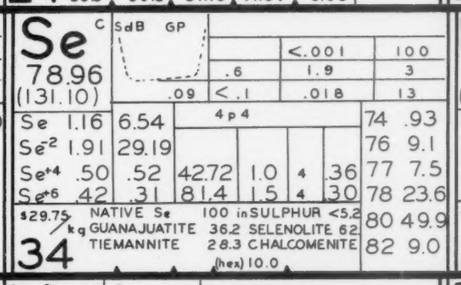


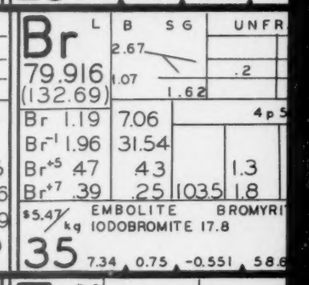


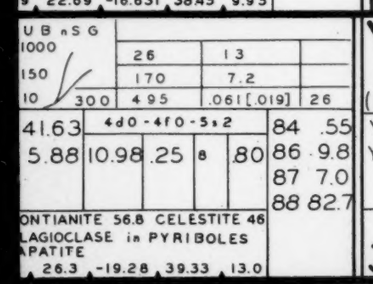


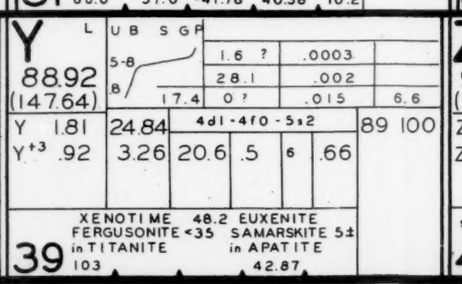


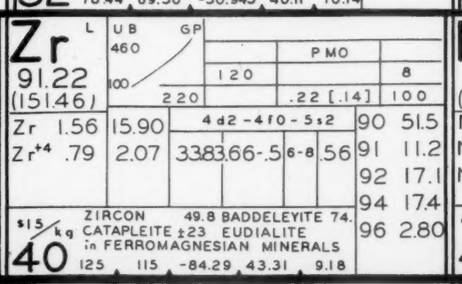


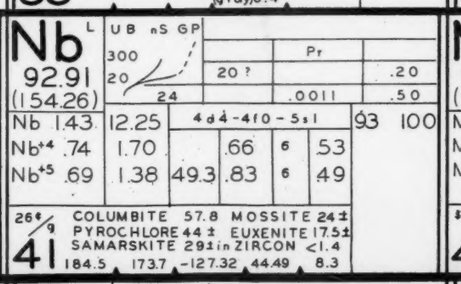


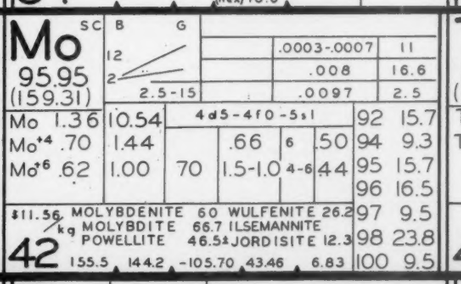


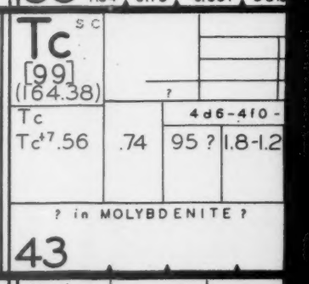












6	7	8	0
RO_3	RH R_2O_7	SERIES	

ELECTROMOTIVE

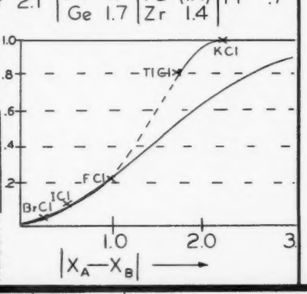
Electrode E°(volts)		Electrode E°(volts)	
Li^{+1}, Li	+3.024	H^{+1}, H_2	0.000
Cs^{+1}, Cs	+3.02	Sb^{+3}, Sb	−.10
Rb^{+1}, Rb	+2.99	Bi^{+3}, Bi	−.226
K^{+1}, K	+2.924	As^{+3}, As	−.30
Ba^{+2}, Ba	+2.90	Cu^{+2}, Cu	−.344
Sr^{+2}, Sr	+2.89	O_2, OH^{-1}	−.401
Ca^{+2}, Ca	+2.87	Cu^{+1}, Cu	−.522
Na^{+1}, Na	+2.714	I_2, I^{-1}	−.535
La^{+3}, La	+2.37	Te^{+4}, Te	−.568
Mg^{+2}, Mg	+2.34	Hg_2^{+2}, Hg	−.7986
Ti^{+2}, Ti	+1.75	Ag^{+1}, Ag	−.799
Be^{+2}, Be	+1.70	Pb^{+4}, Pb	−.80
Al^{+3}, Al	+1.67	Pd^{+2}, Pd	−.83
U^{+4}, U	+1.40	Hg^{+2}, Hg	−.854
Mn^{+2}, Mn	+1.05	Pt^{+4}, Pt	−.863
Te, Te^{-2}	+.92	Br_2, Br^{-1}	−1.087
Zn^{+2} Zn	+.761	Pt^{+2}, Pt	−1.2 ±
Cr^{+3}, Cr	+.71	Gl_2, Cl^{-1}	−1.358
Ga^{+3}, Ga	+.52	Au^{+3} Au	−1.42
S, S^{-2}	+.508	Au^{+1}, Au	−1.68
Fe^{+2}, Fe	+.441	F_2, F^{-1}	−2.85
Cd^{+2}, Cd	+4021		
In^{+3}, In	+.340		
Tl^{+1}, Tl	+.338		
Co^{+2}, Co	+.277		
Ni^{+2}, Ni	+.250		
Sn^{+2}, Sn	+.140		
Pb^{+2}, Pb	+.126		
Fe^{+3}, Fe	+.036		
H^{+1}, H_2	0000		

Schürmann SOLUBILITY OF SULPHIDES: upper replaces lower — Hg, Ag, Cu, Bi, Cd, Pb, Zn, Ni, Co, Fe^{+2}, Mn

Fournet & Schütz AFFINITY FOR S IN MELT: increasing affinity — Mn, Cu, Ni, Co, Fe, Sn, Zn, Pb, Sb, Ag

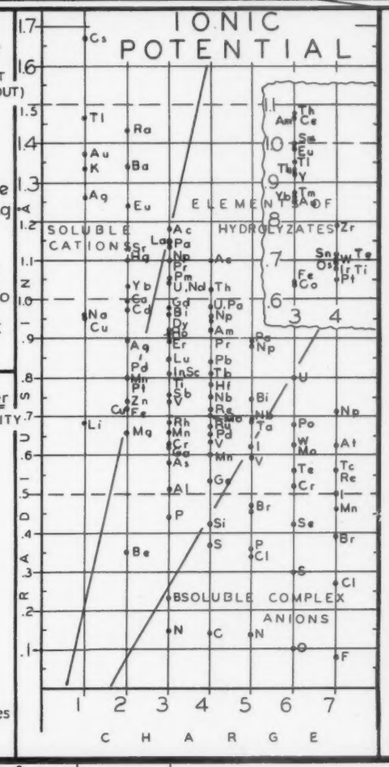
ELECTRONEGATIVITY(x)

F 4.0	Cr^{+6} 2.1	Fe^{+2} 1.65	V^{+3} 1.35		
O 3.5	Ru 2.05	Sn^{+2} 1.65	Hf (1.3)		
Cl 3.0	Pd 2.0	V^{+4} 1.6	Sc 1.3		
N 3.0	Cu^{+2} 2.0	Nb (1.6)	U 1.3		
Br 2.8	As 2.0	Mo^{+4} (1.6)	Y 1.2		
I 2.6	Po (2.0)	In 1.6	Mg 1.2		
C 2.5	B 2.0	Pb^{+2} 1.6	Th 1.1		
S 2.5	Tl^{+3} 1.9	W^{+4} (1.6)	Pr 1.1		
At (2.4)	Hg^{+2} 1.9	Ga 1.6	Ce 1.05		
Mn^{+2} (2.3)	Bi 1.8	Cr^{+3} 1.6	Ac (1.0)		
Se 2.3	Pb^{+4} 1.8	Ti^{+4} 1.6	Sr 1.0		
Au 2.3	Hg^{+1} 1.8	Cd 1.5	Ca 1.0		
H 2.1	Sb^{+3} 1.8	Zn 1.5	Li 1.0		
P 2.1	Sn^{+4} 1.8	Be 1.5	Na .9		
Mo^{+3} (2.1)	Cu^{+1} 1.8	Al 1.5	La .85		
Te 2.1	Fe^{+3} 1.8	Cr^{+2} 1.5	Ba .85		
Sb^{+5} 2.1	V^{+5} 1.8	Tl^{+1} 1.5	Ra .8		
Ir 2.1	Si 1.8	Mn^{+3} (1.5)	K .8		
W^{+6} 2.1	Ag 1.8	Mn^{+2} 1.4	Rb .8		
Rh 2.1	Co 1.7	Ta (1.4)	Cs .7		
Os (2.1)	Ni 1.7	Pa (1.4)	Fr .7		
Pt 2.1	Ge 1.7	Zr 1.4			



Zoning (Fe and S PRESENT THROUGHOUT): Hg, Sb, Pb, Zn, [Cu, Se, Ag], As, Au, Te, Bi, U, W, Sn, Mo — HEATED SOURCE

Hofmeister ADSORBABILITY: Li, Na, K, Mg, Ca, Sr, Ba, Al, H — upper replaces lower



He — 4.003 (6.65)

He 1.45 | 12.77 | 1s2 | 3 1.3•10⁻⁴ | 4 ~100

He³ ENR. IN AIR>GAS WELLS: ca. 3•10⁻⁵ | .003 | 349000

$2.83/1000 liters in BERYL in THORIANITE in MAGNETITE in ZIRCON in TITANITE in HALITE | 30.13 | 2

Ne — 20.183 (33.51)

Ne 1.60 | 17.16 | 1s2-2s2-2p6 | 20 90.9 | 21 .26 | 22 8.8

U G: .00007 — .00007 | ca. 3•10⁻⁵ | 2130

$6/liter | 34.95 | 10

A — 39.944 (66.32)

A 1.91 | 29.19 | 3s2-3d6 | 36 .337 | 38 .063 | 40 99.60

U G: .04 — .04 | .35-.70 | 170

$4.95/1000 liters | 36.98 | 18

F — 19.00 (31.55)

F .68 | 1.32 | 1s2-2s2-2p5 | 19 100

F^{-1} 1.36 | 10.54 | .002 | 184.0

F^{+7} .08

UBIG: 48.5 (%) — 45.1 — 466000 | 4100 | 410200±9500

UBIGP: 1000 — 500 — 100 — 700 | 1.4 | .3 | 510 | 250 | .097 | 40

$1.10-4.40/kg FLUORITE 48.9 CRYOLITE 54.4 TOPAZ 20.7 APATITE 3.8 in AMPHIBOLES, TOURMALINE, MICAS | 9

.90 | 11.49 | .004 | 137.48 | 16 99.76 | 17 .037 | 18 .20

QUARTZ 53.1 HEMATITE 30
LBITE 48.8 ENSTATITE 46.2
UPRITE 11.2 CALCITE 48
(O_2) 49.00

Cl — 35.457 (58.87)

Cl 1.07 | 5.13 | 3s2-3p5 | 35 75.4 | 37 24.6

Cl^{-1} 1.81 | 24.84 | .16 | 67.4 | 1.3 | 4 | .24

Cl^{+5} .34 | .08 | 113.7 | .2 | 3 | .19

Cl^{+7} .27

UBISG: 550 — 400 — 330 — 250 — 314 | UNFRACTIONATED: TRACE | 18980 | 10084 | 200 | 1.27 | 900

$21.5¢/kg APATITE 6.8 HALITE 60.6 CALOMEL 15. SYLVITE 47.6 PYROMORPHITE 2.6 VANADINITE 2.5 | 17

(Cl_2) 53.29

UBIG: 3000 — 2000 — 1000 — 500 — 750 | S^{-2} >34 <22.30 IS BIOGENIC; S^{+6} >22.18 INORGANIC | 2800 | 884 | 343000 | 2600 | 283 | 360 | 1100 | 536 | 179001800

4.71 | 26.52 | .21 | 47.08 | 1.0 | 4 | .26 | .11 | 87.67 | 1.5 | 4 | .21 | 3s2-3p4 | 32 75.4 | 33 .75 | 34 4.2

NATIVE S. 100 PYRITE 53.3
NOSELITE 3.2 LAZURITE 4.2
YRRHOTITE 35.4-41.8 BORNITE 25.6
(rhb) 7.62

Mn — 54.93 (91.20)

Mn 1.18 | 6.88 | 3d5-4s2 | 55 100

Mn^{+2} .80 | 2.14 | 15.70 | .33 | 6 | .57

Mn^{+3} .66 | 1.20 | 32? | .5 | 6 | .47

Mn^{+4} .60 | .90 | 52? | 10-66 | 4-6 | 43

Mn^{+7} .46 | 41 -122 | 1.8 | 4 | .33

UBGR: 1200 — 1000 — 1000 | TRACE | 001-.01 | 460 | 620 | .002 | 300 | 385 | 6.38 | 2960±670

$3.75/kg PYROLUSITE 63.2 RHODONITE 42 RHODOCHROSITE 47.8 TRIPLITE var ALABANDITE 63.2 FRANKLINITE 36 | 25

68.34 | 58.23 | -42.682 | 41.49 | 7.59

UBIG: 2000 — 400 — 200 | 68-200 | PMO | 1200 | 410-680 | 240 | 2 | 7.29 | 3450±590

8.18 | 1.05 | .59 | 3d5-4s1 | -32.1 | .5 | 6 | .45 | 96. | 1.5 | 4 | .37 | 50 4.4 | 52 83.7 | 53 9.5 | 54 24

CHROMITE 46.2 in DIOPSIDE <2
CROCOITE 16.1 FUCHSITE
UVAROVITE 20.9 in EPIDOTE
0.5 | 69.8 | -51.16 | 41.64 | 5.68

Fe — 55.85 (92.73)

Fe 1.24 | 7.99 | 3d6-4s2 | 54 5.9

Fe^{+2} .74 | 1.70 | 16.24 | .33 | 6 | .53

Fe^{+3} .64 | 1.10 | .5 | 6 | 46

UBIG: 11 — 9 — 2.5 | UNFRACTIONATED: 9900 | .002-.02 | 611000 | 47300 | .00007 | 907800 | 5000 | 4000 | 639 | 156400±5400

$8.20/kg HEMATITE 70 GLAUCONITE 14± PYRITE 46.7 MELANTERITE 20 SIDERITE 48.4 LIMONITE 59.8 | 26

96.68 | 85.76 | -62.861 | 43.11 | 6.49

UBIG: 237 — 24 — 8 | 0 | .0001 | 100 | 8 | .0007 | 6300±200 | 23 | 0 | 2.92 | 206±86

Co — 58.94 (97.86)

Co 1.25 | 8.18 | 3d7-4s2 | 59 100

Co^{+2} .72 | 1.56 | 17.3 | .33 | 6 | .51

Co^{+3} .63 | 1.05 | .5 | 6 | .45

$14.33/kg SMALTITE 28.2 LINNAEITE 58 COBALTITE 35.5 ERYTHRITE 29.5 in ARSENOPYRITE | 27

105 | 94 | -68.9 | 42.88 | 6.8

UBIG: 3000 — 50 — 2 — 80 | 2-8 ? | .0001-.0005 | 100 | 24 ? | .001 | 8590±2400 | 0 ? | 39.1 | 1380±240

Ni — 58.69 (97.45)

Ni 1.24 | 7.99 | 3d8-4s2 | 58 67.9

Ni^{+2} .69 | 1.38 | 18.13 | .33 | 6 | .49 | 60 26.2 | 61 1.2 | 62 3.7 | 64 1.0

$10/kg GARNIERITE 25-30 MILLERITE 64.4 NICCOLITE 43.9 CHLOANTHITE 28.1 ANNABERGITE 29.5 in PYRRHOTITE | 28

101.61 | 90.77 | -66.533 | 43.59 | 7.20

Br — 79.916 (132.69)

Br 1.19 | 7.06 | 4p5 | 79 50.6

Br^{-1} 1.96 | 31.54 | 1.3 | 4 | .34 | 81 49.4

Br^{+5} .47 | 4.3

Br^{+7} .39 | 25 | 103.5 | 1.8 | 4 | .28

B S G: 2.67 — 1.07 | UNFRACTIONATED: .2 | 6587 | 1 | 1.62 | .067 | 25

$5.47/kg EMBOLITE BROMYRITE 42.2 IODOBROMITE 17.8 | 35

7.34 | 0.75 | -0.551 | 58.64 | 36.4

SdB GP: .6 | 1.9 | 3 | .09 | <.1 | .018 | 13

16 | 6.54 | 91 | 29.19 | 50 | .52 | 42.72 | 1.0 | 4 | .36 | 42 | .31 | 81.4 | 1.5 | 4 | .30 | 74 .93 | 76 9.1 | 77 7.5 | 78 23.6 | 80 49.9 | 82 9.0

NATIVE Se 100 in SULPHUR <5.2
GUANAJUATITE 36.2 SELENOLITE 62
TIEMANNITE 28.3 CHALCOMENITE
(hex) 10.0

ALL ABUNDANCE DATA GIVEN IN GRAMS PER METRIC TON

[1 g/ton = 1 p.p.m. = .0001% = 10^{-6} g/g]

ABBREVIATIONS

B-basaltic and/or gabbroic	PMO-present in marine organisms
ENR.-enriched	PPT-precipitated
G-granitic and/or rhyolitic	Pr-present
GR-greisen	S-syenitic
I-dioritic and/or granodioritic	Sd-sulphide
nS-nepheline syenitic	SEDS.-sediments
P-pegmatitic	U-ultrabasic

Kr — 83.80 (139.14)

Kr 2.0 | 33.51 | 4p6 | 78 .35 | 80 227 | 82 11.5 | 83 11.5 | 84 57.0 | 86 17.4

$45/liter | 39.19 | 36

Tc — [99] (164.38)

Tc

Tc^{+7} 56 | .74 | 95 ? | 1.8-1.2 | 4-6 | 40 | 4d6-4f0-5s1 | 99 ? | 2.1•10⁵y β⁻

? in MOLYBDENITE ?

SC: ? — ? | 43

B G: 12 — 2 — 2.5-15 | .0003-.0007 | 11 | .008 | 16.6 | .0097 | 2.5

36 | 10.54 | 70 | 1.44 | 62 | 1.00 | 4d5-4f0-5s1 | 92 15.7 | 94 9.3 | 95 15.7 | 96 16.5 | 97 9.5 | 98 23.8 | 100 9.5

MOLYBDENITE 6.0 WULFENITE 26.2
MOLYBDITE 66.7 ILSEMANNITE
POWELLITE 46.5± JORDISITE 12.3
155.5 | 144.2 | -105.70 | 43.46 | 6.83

Ru — 101.7 (168.9)

Ru 1.33 | 9.85 | 4d7-4f0-5s1 | 96 5.7

Ru^{+4} .67 | 1.26 | .66 | 6 | .48 | 98 222 | 99 12.8 | 100 12.7 | 101 17.0 | 102 31.3 | 104 18.3

SdU B G: 1 — 0 — Pr | 4.2 | 10.6 | .0037 | 0

$7.00/g NATIVE Ru LAURITE 5.9 in CHROMITE | 44

160 | 149 | -109.2 | 44.57 | 6.9

Rh — 102.91 (170.87)

Rh 1.34 | 10.08 | 4d8-4f0-5s1 | 103 100

Rh^{+3} .68 | 1.32 | .5 | 6 | .49

SdU B G: .3 — 0 | 1.0 | 4.1 | 0 | .001 | .0012 | 0

$10/g NATIVE Rh RHODITE 34-43 in CHROMITE | 45

138 | 127 | -93.09 | 44.39 | 7.6

Pd — 106.7 (177.2)

Pd 1.37 | 10.77 | 4d10 | 102 .8 | 104 9.3 | 105 22.6 | 106 27.1 | 108 26.7 | 110 13.5

Pd^{+2} .80 | 2.14 | 19.8 | .33 | 6 | .57

Pd^{+4} .65 | 1.15 | .66 | 6 | 46

SdU B G: 4 — 0 | 4.5 | 3.7 | 0 | .010 | .0024 | 0

$77¢/g NATIVE Pd STIBIOPALLADINITE 72.4 BRAGGITE 19 ± PORPEZITE 10 POTARITE ca. 33 ? | 46

93 | 84 | -61.6 | 39.91 | 8.9

I — 126.91 (210.72)

I 1.36 | 10.54 | 4f0-5s2-5p5 | 127 100

B G: 2 — 3 | .05 | 2.8 | .6 | .3 | .07-.55 | .0033 | 1.26

KEY

S-SIDEROPHILE
C-CHALCOPHILE

ROCK TYPE

Xe — 131.3 (218.0)

Xe

4f0-5s2-5p6 | 124 .096

Iodine	I	53
Ionium-isotope of thorium[230]		
Iridium	Ir	77
Iron	Fe	26
Kalium-potassium		
Krypton	Kr	36
Lanthanum	La	57
Lead	Pb	82
Lithium	Li	3
Lutecium	Lu	71
Magnesium	Mg	12
Manganese	Mn	25
Masurium-technetium		
Mercury	Hg	80
Molybdenum	Mo	42
Natrium-sodium		
Nebulium-hypothetical cosmic element		
Neodymium	Nd	60
Neoytterbium-ytterbium		
Neptunium	Np	93
Neon	Ne	10
Nickel	Ni	28
Niobium	Nb	41
Niton-radon		
Nitrogen	N	7
Osmium	Os	76
Oxygen	O	8
Palladium	Pd	46
Phosphorus	P	15
Platinum	Pt	78
Plumbum-lead		
Plutonium	Pu	94
Polonium	Po	84
Potassium	K	19
Praseodymium	Pr	59
Promethium	Pm	61
Protactinium	Pa	91
Radium	Ra	88
Radium emanation-radon		
Radium F-polonium		
Radon	Rn	86
Rhenium	Re	75
Rhodium	Rh	45
Rubidium	Rb	37
Ruthenium	Ru	44
Samarium	Sm	62
Scandium	Sc	21
Selenium	Se	34
Silicon	Si	14
Silver	Ag	47
Sodium	Na	11
Stannum-tin		
Stibium-antimony		
Strontium	Sr	38
Sulfur	S	16
Tantalum	Ta	73
Technetium	Tc	43
Tellurium	Te	52
Terbium	Tb	65
Thallium	Tl	81
Thorium	Th	90
Thulium	Tm	69
Thoron-isotope of radon[220]		
Tin	Sn	50
Titanium	Ti	22
Tritium-isotope of hydrogen[3]		
Tungsten-wolfram		
Uranium	U	92
Vanadium	V	23
Virginium-francium		
Wolfram	W	74
Wolframium-wolfram		
Xenon	Xe	54
Ytterbium	Yb	70
Yttrium	Y	39
Zinc	Zn	30
Zirconium	Zr	40

Densità d'abondance en grammes par tonne — Gehalt-Daten in Grammen per Tonne — Soderzhanie v grammakh na tonnu — Datos de abundancia en gramos por tonelada métrica

CLEF — ZEICHENERKLÄRUNG — USLOVNIE OBOZNACHENIYA — LLAVE

Élément	basaltique	granitique	A G I A
Element	basaltisch	granitisch	B E Z B
Element	basaltichesky	granitiy	O H O U
Elemento	basáltico	granítico	N A B N
			D L I D
Poids atomique	Conduite pendant la différentiation		A T L A
Atomgewicht	Verhalten während die Differentiation		N I N
Atomniy ves	Povedenie vo vremya differentsiatsii		C C
Peso atómico	Conducta durante la diferenciación		E I
			A
Poid d'un atome	Roches ignés		
Gewicht eines Atoms	Erstarrungsgesteine		
Ves odnogo atoma	Vulkanicheskie gornie porodi		
Peso de un átomo	Rocas ígneas		
(× 10^{-24})			

Donnés isotopiques (non-radiogéniques)
Isotopisch Daten (nicht-radiogenisch)
Dannie ob isotopakh (ne radioaktivnikh)
Datos para los isótopos no radiogénicos

Grès	Océan	Sulfid météorique
Sandstein	Ozean	Meteorsulfid
Peschanik	Okean	Meteoriy sulfid
Arenisca	Océano	Sulfuro meteórico
Argile schisteuse	Transfert %	Fer météorique
Schieferton	Übertrag %	Meteoreisen
Slantsevataya glina	Perenos %	Meteornoe zheleso
Lutita	Transbordo %	Hierro meteórico
Calcaire	Univers	Silicat météorique
Kalkstein	Universum	Meteorsilikat
Iavestnyak	Vselennaya	Meteoriy silikat
Caliza	Cosmos	Silicato meteórico

Atome
Atom
Atom
Atomo

Ions — Rayon (Å)
Ionen — Radii
Ioni — Luch
Iones — Radius

Volume (Å³)
Volumen
Ob"em
Volumenes

Electrons dans chaque groupe quantum
Elektronen in jeder Quantumgruppe
Elektroni v kazhdoy kvantovoy gruppe
Electrones en cada grupo quantum

Potentielle ionisation	Valance électrostatique	Coordination Zuordnung	Rayon Rapport
Potentielle Ionisierung	Valenz elektrostatische	Koordinatsiya	Radius Verhältnis
Potentsialnaya ionizatsiya	Valentnost elektrostaticheskaya	Coordinaciones	Luch otnoshenie
Potenciales de ionización	Valencias electrostáticas		Proporción de los radios

Isotope naturel
Natürliche Isotope
Estestvenniy izotop
Isótopo natural

Isotope radioactif
Radioaktive Isotope
Radioaktivniy izotop
Isótopo radioactivo

Prix en détail pour élement pur
Kleinhandelspreis für reinen Element
Roznichnaya tsena za chistiy element
Costo menudeo por elemento puro

Minéral avec % d'élément contenu
% Gehalt des Element im Mineral
Mineral s % soderzhaniya elementa
Minerales con % del elemento contenido

Demie-vie
Halbleben
Polovina zhiz-nennogo sroka
Media vida

Désintégration par radiation
Strahlungsersetzung
Raspad za schet lucheispuskaniya
Desintegración por radiación

Numéro atomique
Atomzahl
Atomnoe chislo
Número atomico

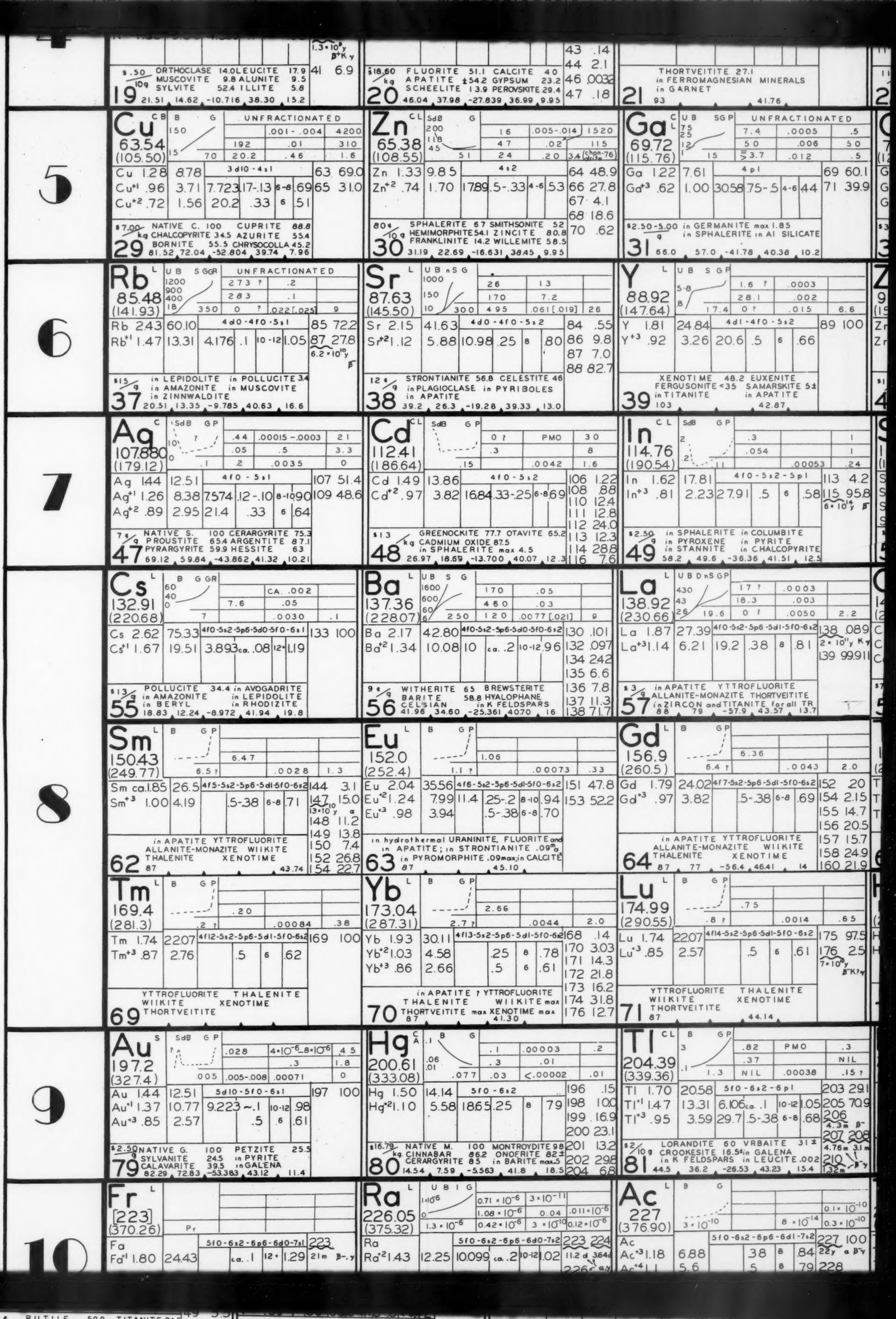
Chaleur de combinaison
Bildungswärme
Teplota obrazovaniya
Calor de formación (gas, gas)

Énergie de formation
Bildungsenergie
Energiya obraozovaniya
Energía libre de formación

Logarithme de constante équilibre
Logarithmus der Gleichgewicht-Konstante
Logarifm postoyannoy
Logaritmo de la constante de equilibro (gas, gas)

Entropie à 25°C. Entropie auf 25°C. Entropiya pri 25°C. Entropía a 25°C. (gas, gas)

Entropie à 25°C. Entropie auf 25°C. Entropiya pri 25°C. Entropía a 25°C. (solide, körperlich, tverdoe telo, solida)



UORITE 51.1 CALCITE 40
ATITE ±54.2 GYPSUM 23.2
HEELITE 13.9 PEROVSKITE 29.4
4 37.98 -27.839 36.99 9.95

46 .0032
47 .18

21

THORTVEITITE 27.1
in FERROMAGNESIAN MINERALS
in GARNET

93 41.76

11¢/g
RUTILE 59.9 TITANITE 24.5
ILMENITE 31.6 PEROVSKITE 35
in PYRIBOLES

22

95 84 -61.6 43.07 7.24

50 5.3

$3/g
VANADINITE 10.8 CARNOTITE 1.1
PATRONITE max 24 ROSCOELITE 2±
COULSONITE <5 - in ASPHALT

23

120 109 -79.90 43.55 7.05

$8.26/kg
CHROMITE 46.2 in DIOPSIDE <2
CROCOITE 16.1 FUCHSITE
UVAROVITE 20.9 in EPIDOTE

24

80.5 69.8 -51.16 41.64 5.68

$3.75/kg
PYROLUSITE 63.2 R
RHODOCHROSITE 47.8 T
ALABANDITE 63.2 FR

25

68.34 58.23 -42.682

SdB G
200 118 45 51
16 .005-.014 1520
47 .02 115
24 .20 3.4 (chan-76) pyrite

9.85 4s2 64 48.9
1.70 1789.5-.33 4-6 .53 66 27.8
67 4.1
68 18.6

HALERITE 67 SMITHSONITE 52
IMORPHITE 54.1 ZINCITE 80.8
ANKLINITE 14.2 WILLEMITE 58.5
9 22.69 -16.631 3845 9.95

70 .62

Ga (69.72) (115.76)

UB SGP 75 25 12 1 15
UNFRACTIONATED
7.4 .0005 .5
50 .006 50
≤3.7 .012 .5

Ga 1.22 7.61 4p1 69 60.1
Ga+3 .62 1.00 30.58 .75-.5 4-6 .44 71 39.9

$2.50-5.00/g in GERMANITE max 1.85
in SPHALERITE in Al SILICATE

31

66.0 57.0 -41.78 40.38 10.2

Ge (72.60) (120.54)

B GGR 35 3.5 2
3 Pr 600
7 190
.14 10

Ge 1.22 7.61 4p2 70 20.4
Ge+2 .73 1.63 15.86 .33 6 .52 72 27.4
Ge+4 .53 .62 45.50 1.0 4 .38 73 7.8
74 36.6
76 7.8

$3.00/g ARGYRODITE 5-7 GERMANITE 10
ULTRABASITE 2.2 in SPHALERITE

32

78.44 69.50 -50.943 40.11 10.14

As (74.91) (124.38)

SdB GP 2000 5 0 5
as ARSENITE .003-.024 1000
ca 5 .8 360
.049 20

As 1.25 8.18 4p3 75 100
As+3 .58 .82 28.19 .75-.5 4-6 41
As+5 .46 41 62.4 1.3 4 .33

$5.24/kg ARSENOPYRITE 46
SMALTITE 71.8 ORPIMENT 61
COBALTITE 45.2 NICCOLITE 55.9

33

(gray) 8.4

Se (78.96) (131.10)

SdB GP
<.001 100
.6 1.9 3
.09 <.1 .018 13

Se 1.16 6.54 4p4 74 .93
Se-2 1.91 29.19 76 9.1
Se+4 .50 .52 42.72 1.0 4 .36 77 7.5
Se+6 .42 .31 81.4 1.5 4 .30 78 23.6
80 49.9
82 9.0

$29.75/kg NATIVE Se 100 in SULPHUR <5.2
GUANAJUATITE 36.2 SELENOLITE 62
TIEMANNITE 28.3 CHALCOMENITE (hex) 10.0

34

Br (79.916) (132.69)

B SG 2.67 1.07 1.62

Br 1.19 7.06
Br-1 1.96 31.54
Br+5 .47 43 1.3
Br+7 .39 .25 103.5 1.8

$5.47/kg EMBOLITE BRO
IODOBROMITE 17.8

35

7.34 0.75 -0.551

UB nSG 1000 150 10 300
26 13
170 7.2
4.95 .061 [.019] 26

41.63 4d0-4f0-5s2 84 .55
5.88 10.98 .25 8 .80 86 9.8
87 7.0
88 82.7

ONTIANITE 56.8 CELESTITE 46
LAGIOCLASE in PYRIBOLES
APATITE
26.3 -19.28 39.33 13.0

Y (88.92) (147.64)

UB SGP 5-8 8 17.4
1.6 ? .0003
28.1 .002
0 ? .015 6.6

Y 1.81 24.84 4d1-4f0-5s2 89 100
Y+3 .92 3.26 20.6 .5 6 .66

XENOTIME 48.2 EUXENITE
FERGUSONITE <35 SAMARSKITE 5±
in TITANITE in APATITE

39

103 42.87

Zr (91.22) (151.46)

UB GP 460 100 220
120 PMO 8
.22 [.14] 100

Zr 1.56 15.90 4d2-4f0-5s2 90 51.5
Zr+4 .79 2.07 33 83.66-.5 6-8 .56 91 11.2
92 17.1
94 17.4
96 2.80

$15/kg ZIRCON 49.8 BADDELEYITE 74.
CATAPLEITE ±23 EUDIALITE
in FERROMAGNESIAN MINERALS

40

125 115 -84.29 43.31 9.18

Nb (92.91) (154.26)

UB nS GP 300 20 24
20? Pr .20 -
.0011 .50

Nb 1.43 12.25 4d4-4f0-5s1 93 100
Nb+4 .74 1.70 .66 6 .53
Nb+5 .69 1.38 49.3 .83 6 .49

26¢/g COLUMBITE 57.8 MOSSITE 24±
PYROCHLORE 44 ± EUXENITE 17.5±
SAMARSKITE 29± in ZIRCON <1.4

41

184.5 173.7 -127.32 44.49 8.3

Mo (95.95) (159.31)

SC B G 12 2 2.5-15
.0003-.0007 11
.008 16.6
.0097 2.5

Mo 1.36 10.54 4d5-4f0-5s1 92 15.7
Mo+4 .70 1.44 .66 6 .50 94 9.3
Mo+6 .62 1.00 70 1.5-1.0 4-6 .44 95 15.7
96 16.5
97 9.5
98 23.8
100 9.5

$11.56/kg MOLYBDENITE 60 WULFENITE 26.2
MOLYBDITE 66.7 ILSEMANNITE
POWELLITE 46.5± JORDISITE 12.3

42

155.5 144.2 -105.70 43.46 6.83

Tc [99] (164.38)

SC ?
Tc 4d6-4
Tc+7 .56 .74 95 ? 1.8

? in MOLYBDENITE ?

43

SdB GP
0? PMO 30
.3 8
.15 .0042 1.6

13.86 4f0-5s2 106 1.22
3.82 16.84 .33-.25 6-8 .69 108 .88
110 12.4
111 12.8
112 24.0
113 12.3
114 28.8
116 7.6

REENOCKITE 77.7 OTAVITE 65.2
ADMIUM OXIDE 87.5
SPHALERITE max 4.5
7 18.69 -13.700 40.07 12.3

In (114.76) (190.54)

CL SdB GP 2 .2 11
.3 .054 .00053 1
.24

In 1.62 17.81 4f0-5s2-5p1 113 4.2
In+3 .81 2.23 27.91 .5 6 .58 115 95.8 6×10^14 y β⁻

$2.50/g in SPHALERITE in COLUMBITE
in PYROXENE in PYRITE
in STANNITE in CHALCOPYRITE

49

58.2 49.6 -36.36 41.51 12.5

Sn (118.70) (197.08)

SC L UB nS G GR 8000 80 8 0 40
.003 [15] .16 ?
.01 77
.037 3

Sn 1.40 11.49 4f0-5s2-5p2 112 .95
Sn+4 2.15 41.63 114 .65
Sn+2 .93 3.37 14.52 33 6 .66 115 .34
Sn+4 .71 1.50 40.57 .66 6 .51 116 14.2
117 7.6
118 24.0
119 8.6
120 33.0
122 4.7
124 6.0

$8.86/kg CASSITERITE 78.6 STANNITE 27.5
CYLINDRITE 24.8 TEALLITE 28.1
in SPHALERITE in GALENA

50

72 64 -47.6 40.25 12.3

Sb (121.76) (202.17)

C SdB GP 3 .1 0 1
1 PMO 7.8
3 2
.0016 .1

Sb 1.45 12.77 4f0-5s2-5p3 121 57.2
Sb+3 .76 1.84 24.7 .5 6 .54 123 42.8
Sb+5 .62 1.00 55.4 1.3-.83 4-6 .44

$6.60/kg STIBNITE 71.8 NATIVE Sb 100
PYRARGYRITE 22.2 TETRAHEDRITE 24.8
SENARMONTITE 83.6 in GALENA

51

60.8 51.1 -37.46 43.06 10.5

Te (127.61) (211.88)

C SdB GP ? .0018? .00035 chan-drite .13
1.7

Te 1.43 12.25 4f0-5s2-5p4 120 .091
Te-2 2.11 39.35 122 2.5
Te+4 .70 1.44 37.7 .66 6 .50 123 .88
Te+6 .56 .74 72.0 1.5-1.0 4-6 .40 124 4.6
125 7.0
126 18.7
128 31.8
130 34.4

$12.12/kg NATIVE Te 100 TELLURITE 80
CALAVERITE 56.4 SYLVANITE 64
HESSITE 37.2 TEINITE

52

47.6 38.1 -27.93 43.64 11.88

I (126.91) (210.72)

LAB B G .2 .3
.3 .07-

I 1.36 10.54 4f0-5
I-1 2.20 44.60
I+5 .62 1.00 1.3-
I+7 .50 .52 90.2 1.

$12/kg IODYRITE 54.1 MA
LAUTARITE 59

53

14.88 4.63 -3.394

UB S G 600 300 150 250
170 .05
460 .03
120 .0077 [.021] 9

42.80 4f0-5s2-5p6-5d0-5f0-6s2 130 .101
10.08 10 ca. .2 10-12 .96 132 .097
134 2.42
135 6.6
136 7.8
137 11.3
138 71.7

ERITE 65 BREWSTERITE
TE 58.8 HYALOPHANE
IAN in K FELDSPARS
34.60 -25.361 40.70 16

La (138.92) (230.66)

L UB DnS GP 430 43 26 19.6
17? .0003
18.3 .003
0? .0050 2.2

La 1.87 27.39 4f0-5s2-5p6-5d1-5f0-6s2 138 .089
La+3 1.14 6.21 19.2 .38 8 .81 2×10^11 y Ky
139 99.911

$3/g in APATITE YTTROFLUORITE
ALLANITE-MONAZITE THORTVEITITE
in ZIRCON and TITANITE for all TR

57

88 79 -57.9 43.57 13.7

Ce (140.13) (232.67)

L U SGP 8 6.5 0
24? .0004
46.1 .001
24.7 0? .0055 [.012] 2.5

Ce 1.82 25.25 4f1-5s2-5p6-5d1-5f0-6s2 136 .19
Ce+3 1.07 5.13 .5-.38 6-8 .66 138 .26
Ce+4 .94 3.48 36.7 .66-.5 6-8 .67 140 88.47
142 11.08

$79/kg in APATITE max YTTROFLUORITE^ma
ALLANITE-MONAZITE max WIIKITE^a
THALENITE THORTVEITITE

58

85 13.8

Pr (140.92) (233.98)

L B GP 5.5?
5.53
.0023 1

Pr 1.82 25.25 4f2-5s2-5p6-5d1-5f0-6s2 141 100
Pr+3 1.06 4.99 .5-.38 6-8 .76
Pr+4 .92 3.26 .66-.5 6-8 .66

in APATITE YTTROFLUORITE
ALLANITE-MONAZITE WIIKITE
THALENITE THORTVEITITE

59

87

Nd (144.27) (239.54)

L UB SGP 60 26 0
17?
23.9
18.1 0? .0081 3.7

Nd 1.82 25.25 4f3-5s2-5p6-5d1-5f0-6s2 142 27.1
Nd+3 1.04 4.71 .5-.38 6-8 .74 143 12.2
144 23.9
145 8.3
146 17.2
148 5.7
150 5.6

+Pr in APATITE submax THALENITE
$6.50/g YTTROFLUORITE sub max WIIKITE
ALLANITE MONAZITE sub max THORTVEITITE

60

87

Pm [145] (240.75)

L ?
Pm 4f4-5s2-5p6
Pm+3 1.06 4.99 .5-.3

UNKNOWN IN NAT

61

B GP 1.1 ?
1.06
.00073 .33

35.56 4f6-5s2-5p6-5d1-5f0-6s2 151 47.8
7.99 11.4 .25-.2 8-10 .94 153 52.2
3.94 .5-.38 6-8 .70

rmal URANINITE, FLUORITE and
TE; in STRONTIANITE .09^ma
ROMORPHITE .09 max in CALCITE^a
45.10

Gd 156.9 (260.5)

B GP 6.4 ?
6.36
.0043 2.0

Gd 1.79 24.02 4f7-5s2-5p6-5d1-5f0-6s2 152 .20
Gd+3 .97 3.82 .5-.38 6-8 .69 154 2.15
155 14.7
156 20.5
157 15.7
158 24.9
160 21.9

in APATITE YTTROFLUORITE
ALLANITE-MONAZITE WIIKITE
THALENITE XENOTIME

64

87 77 -56.4 46.41 14

Tb 159.2 (264.33)

L B GP .9 ?
.91
.0014 .65

Tb 1.77 23.23 4f8-5s2-5p6-5d1-5f0-6s2 159 100
Tb+3 .93 3.37 .5-.38 6-8 .66
Tb+4 .81 2.23 .66 6 .58

in APATITE YTTROFLUORITE
THALENITE XENOTIME
WIIKITE

65

87

Dy 162.46 (269.74)

L B GP 4.5 ?
4.47
.0056 2.5

Dy 1.77 23.23 4f9-5s2-5p6-5d1-5f0-6s2 156 .052
Dy+3 .92 3.26 .5-.38 6-8 .66 158 .090
160 2.29
161 18.9
162 25.5
163 25.0
164 28.2

in APATITE YTTROFLUORITE
THALENITE max WIIKITE submax
XENOTIME

66

Ho 164.94 (273.86)

L B GP 1.2 ?
1.15
.0016 .72

Ho 1.76 22.84 4f10-5s2-5p6-5d1-5f0-6s2 165 100
Ho+3 .91 3.16 .5-.38 6-8 .65

in APATITE ? YTTROFLUORITE ?
THALENITE WIIKITE
XENOTIME

67

Er 167.2 (277.6)

L B GP 2.5 ?
2.47

Er 1.75 22.45 4f11-5s2-5p
Er+3 .89 2.95 .5

in APATITE YTTRO
THALENITE submax W
XENOTIME submax

68

B GP 2.7 ?
2.66
.0044 2.0

30.11 4f13-5s2-5p6-5d1-5f0-6s2 168 .14
4.58 .25 8 .78 170 3.03
2.66 .5 6 .61 171 14.3
172 21.8
173 16.2
174 31.8
176 12.7

APATITE ? YTTROFLUORITE
LENITE WIIKITE max
TVEITITE max XENOTIME max
41.30

Lu 174.99 (290.55)

L B GP .8 ?
.75
.0014 .65

Lu 1.74 22.07 4f14-5s2-5p6-5d1-5f0-6s2 175 97.5
Lu+3 .85 2.57 .5 6 .61 176 2.5 7×10^9 y β⁻K?γ

YTTROFLUORITE THALENITE
WIIKITE XENOTIME
THORTVEITITE

71

87 44.14

Hf 178.6 (296.5)

L B GP 4.5 3 ?
.0043 1

Hf 1.58 16.52 5d2-5f0-6s2 174 .18
Hf+4 .78 1.99 31 .66 6 .56 176 5.2
177 18.4
178 27.1
179 13.8
180 35.3

in ZIRCON in THORTVEITITE
in BADDELEYITE

72

44.65 13.1

Ta 180.88 (300.33)

L UB SGP 4 1 2.1
.06
.00080 .38

Ta 1.43 12.25 5d3-5f0-6s2 181 100
Ta+5 .68 1.32 44.8 .83 6 .49

$110/kg TANTALITE 70.6 MICROLITE 60±
TAPIOLITE 78 ± FERGUSONITE <4.4
in TITANITE <.1 in ZIRCON

73

185 175 -128.3 44.24 9.9

W (183.92) (305.37)

LS 80 [7] [1] 10
B GP 1.5-69
1-2 ? Pr TRACE
.041 8.1
18

W 1.36 10.54 5d4-5f0-6s2 180 .14
W+4 .70 1.44 .66 6 .50 182 26.2
W+6 .62 1.00 61 .66-1. 4-6 .44 183 14.3
184 30.7
186 28.7

$22/kg WOLFRAMITE 60.7 HÜBNERITE 60.7
SCHEELITE 63.9 FERBERITE 60.7
STOLZITE 40.5 in COLUMBITE

74

201.6 191.6 -140.44 41.55 8.0

Re (186.31) (309.34)

S SdB GP .02 .0001
<.00
<.00
.001

Re 1.38 11.01 5d5-5
Re+4 .72 1.56
Re+7 .56 .74 79.? 1.8

$4/g in MOLYBDENITE .25 in C
in GADINOLITE 10^-4 in
in COLUMBATES 10^-4 in T

75

189 179 -131.2 4

Tl (204.39) (339.36)

CL B GP 3 .1 1.3
.82 PMO .3
.37 NIL
NIL .00038 .15?

Tl 1.70 20.58 5f0-6s2-6p1 203 29.1
Tl+1 1.47 13.31 6.106 ca. .1 10-12 1.05 205 70.9
Tl+3 .95 3.59 29.7 .5-.38 6-8 .68 206 4.3m β⁻
207 208
4.76m 3.1m
210 1.32m β⁻γ

$2/10g LORANDITE 60 VRBAITE 31 ±
CROOKESITE 16.5^4 in GALENA
in K FELDSPARS in LEUCITE .002

81

44.5 36.2 -26.53 43.23 15.4

Pb (207.21) (344.04)

CSL B G 30 5
20 .004-.005 20
20 .05 60
16 5-10 <.007 2

Pb 1.75 22.45 5f0-6s2-6p2 204 1.3
Pb+4 2.15 41.63 206 26.
Pb+2 1.20 7.24 15.04 ca. .2 8-10 .86 207 21.
Pb+4 .84 2.48 43.93 .66 6 .60 208 52.
210
22y β⁻γ ε
211
36.1m β⁻γ
212 214
10.6h 26.8m

$3.55/kg GALENA 86.6 PYROMORPHITE 76.6
CERUSSITE 77.7 ANGLESITE 73.6
CROCOITE 64.1 WULFENITE 56.5

82

46.34 38.47 -28.198 41.89 15.51

Bi (209.00) (347.01)

C SdB GP .3 .2 .1
.3 .0002 2
1 .2 .5
.2 .00005 .02

Bi 1.55 15.60 5f0-6s2-6p3 209 100
Bi+3 .96 3.71 25.42 .5-.38 6-8 .69 3×10^7 y α
210
5.0 d β⁻
211
2.16 m αβ⁻γ
Bi+5 .74 1.70 55.7 1.2 6 .53 212
60.5 m β⁻αγ
214
19.7 m β⁻αγ

$12.57/kg BISMUTHINITE 40.6
NATIVE B. 100
GUANAJUATITE 63.8

83

49.7 40.4 -29.61 44.67 13.6

Po (210) (348.68)

L 3×10^-10 8×10^-14 3×10^-11
1×10^-11

Po 1.41 11.74 5f0-6s2-6p4 210 211m
Po+6 .67 1.26 1.0 6 .48 138.3d .52α
212
3×10^-7 s α
214 215
1.64×10^-4 s 1.83
216 218
0.16 s 3.05m
α β⁻

in URANIUM MINERALS

84

At (210) (348.68)

LS Pr
At 5f0-6
At+7 .62 1.00 1.8-

?

85

UBIG 10^-6
0.71×10^-6 3×10^-11
1.08×10^-6 0.04 .011×10^-6
1.3×10^-6 0.42×10^-6 3×10^-10 0.12×10^-6

5f0-6s2-6p6-6d0-7s2 223 224
2.25 10.099 ca. .2 10-12 1.02 11.2 d 3.64d
226 α γ
1620 y
228

ANIUM MINERALS

Ac (227) (376.90)

L B G 3×10^-10 8×10^-14 0.1×10^-10 0.3×10^-10

Ac
Ac+3 1.18 6.88 5f0-6s2-6p6-6d1-7s2 227 100
Ac+4 1.1 5.6 .38 8 .84 22y α β⁻γ
.5 8 .79 228
6.13h β⁻γ

in URANIUM MINERALS

Th (232.12) (385.40)

L B G 10 4 11.5?
6.1 1-10×10^-6 0
10.1 .00015 .04
1.1 .0023 [.005] 2

Th 1.80 24.43 5f1-6s2-6p6-6d1-7s2 227 228
Th+3 1.08 5.28 29.4 .38 8 .77 18.6d 1.90y
Th+4 1.02 4.45 .66-.5 6-8 .73 230 α γ
8.0×10^4 y
231
25.6h β⁻γ ε
232 100

4.0¢/kg in MONAZITE 7.9 THORITE 41.3

Pa (231) (383.54)

L B G 8×10^-7 2×10^-10 2×10^-8 8×10^-8

Pa
Pa+3 1.13 6.04 5f2-6s2-6p6-6d1-7s2 231 100
Pa+4 .98 3.94 .38 8 .81 3.4×10^4 y α γ
Pa+5 .89 2.95 .66-.5 6-8 .70 234m
.83 6 .63 1.14 m β⁻IT γ
234

U (238.07) (395.28)

LC B G 4 .8 4
U238/235 CONSTANT
1.2 6×10^-4 0
1.2 .3 .007
1.3 .000054? .1

U 1.38 11.01 5f3-6s2-6p6-6d1-7s2 234 .0057
U+3 1.04 4.71 .5-.38 6-8 .74 2.6×10^5 y αγ
U+4 .97 3.82 .66-.5 6-8 .69 235 0.71
U+6 .80 2.14 1.0 6 .57 7.1×10^8 y αγ

Np [237] (393.50)

L Pa?
Np 5f4-6s2-6p
Np+3 1.10 5.58 .38
Np+4 .95 3.59 .66-
Np+5 .88 2.85 .83
Np+7 .71 1.50 1.2

ALL ABUNDANCE DATA GIVEN IN GRAMS PER METRIC TON

[1 g/ton = 1 p.p.m. = .0001% = 10^{-6} g/g]

ABBREVIATIONS

B-basaltic and/or gabbroic
ENR.-enriched
G-granitic and/or rhyolitic
GR-greisen
I-dioritic and/or granodioritic
nS-nepheline syenitic
P-pegmatitic
PMO-present in marine organisms
PPT-precipitated
Pr-present
S-syenitic
Sd-sulphide
SEDS.-sediments
U-ultrabasic

Se — 34

Selenium — C — SdB GP

78.96 (131.10)

				<.001		100	
			.6	1.9		3	
			.09	<.1	.018	13	
Se 1.16	6.54	4p4				74	.93
Se^{-2} 1.91	29.19					76	9.1
Se^{+4} .50	.52	42.72	1.0	4	.36	77	7.5
Se^{+6} .42	.31	81.4	1.5	4	.30	78	23.6
						80	49.9
						82	9.0

$29.75/kg — NATIVE Se 100 in SULPHUR <5.2; GUANAJUATITE 36.2 SELENOLITE 62; TIEMANNITE 28.3 CHALCOMENITE (hex) 10.0

Br — 35

Bromine — L — B SG

79.916 (132.69)

		UNFRACTIONATED					
				65			
			.2	6687		1	
		1.62		.067		25	
Br 1.19	7.06	4p5				79	50.6
Br^{-1} 1.96	31.54					81	49.4
Br^{+5} .47	43		1.3	4	.34		
Br^{+7} .39	.25	1035	1.8	4	.28		

$5.47/kg — EMBOLITE BROMYRITE 42.2; IODOBROMITE 17.8

7.34 | 0.75 | -0.551 | 58.64 | 36.4

Mo — 42

Molybdenum — SC — B G

95.95 (159.31)

				.0003-.0007		11	
				.008		16.6	
		2.5-15		.0097		2.5	
Mo 1.36	10.54	4d5-4f0-5s1				92	15.7
Mo^{+4} .70	1.44		.66	6	.50	94	9.3
Mo^{+6} .62	1.00	70	1.5-1.0	4-6	.44	95	15.7
						96	16.5
						97	9.5
						98	23.8
						100	9.5

$11.56/kg — MOLYBDENITE 60 WULFENITE 26.2; MOLYBDITE 66.7 ILSEMANNITE; POWELLITE 46.5 JORDISITE 12.3

155.5 | 144.2 | -105.70 | 43.46 | 6.83

Tc — 43

Technetium — SC

[99] (164.38)

		?			?		
Tc		4d6-4f0-5s1				99 ?	2.1×10^5 y β⁻
Tc^{+7} 56	.74	95 ?	1.8-1.2	4-6	.40		

? in MOLYBDENITE ?

9

Ru — 44

Ruthenium — SC — SdU B G

101.7 (168.9)

						4.2	
						10.6	
Pr				.0037		0	
Ru 1.33	9.85	4d7-4f0-5s1				96	5.7
Ru^{+4} .67	1.26		.66	6	.48	98	222
						99	12.8
						100	12.7
						101	17.0
						102	31.3
						104	18.3

$7.00/g — NATIVE Ru LAURITE 59 in CHROMITE

160 | 149 | -109.2 | 44.57 | 6.9

Rh — 45

Rhodium — S — SdU B G

102.91 (170.87)

						1.0	
						4.1	
	.001			.0012		0	
Rh 1.34	10.08	4d8-4f0-5s1				103	100
Rh^{+3} .68	1.32		.5	6	.49		

$10/g — NATIVE Rh RHODITE 34-43 in CHROMITE

138 | 127 | -93.09 | 44.39 | 7.6

Pd — 46

Palladium — SC — SdU B G

106.7 (177.2)

						4.3	
						3.3	
	.010			.0024		0	
Pd 1.37	10.77	4d10				102	
Pd^{+2} .80	2.14	19.8	.33	6	.57	104	
Pd^{+4} .65	1.15		.66	6	.46	105	
						106	
						108	
						110	

77 ¢/g — NATIVE Pd STIBIOPALLADINITE; BRAGGITE 19 ± 72.4; PORPEZITE 10 POTARITE ca. 33 ?

93 | 84 | -61.6 | 39.91 | 8.9

Te — 52

Tellurium — C — SdB GP

127.61 (211.88)

						17	
	.0018?			.00035		chon. .13	
Te 1.43	12.25	4f0-5s2-5p4				120	.091
Te^{-2} 2.11	39.35					122	2.5
Te^{+4} .70	1.44	37.7	.66	6	.50	123	.88
Te^{+6} .56	.74	72.0	1.5-1.0	4-6	.40	124	4.6
						125	7.0
						126	18.7
						128	31.8
						130	34.4

$12.12/kg — NATIVE Te 100 TELLURITE 80; CALAVERITE 56.4 SYLVANITE 64; HESSITE 37.2 TEINITE

47.6 | 38.1 | -27.93 | 43.64 | 11.88

I — 53

Iodine — L A B — B G

126.91 (210.72)

						.05	
						2.8	.6
	.3	.07-.55		.0033		1.26	
I 1.36	10.54	4f0-5s2-5p5				127	100
I^{-1} 2.20	44.60						
I^{+5} .62	1.00		1.3-.83	4-6	.44		
I^{+7} .50	.52	90.2	1.8	4	.36		

$12/kg — IODYRITE 54.1 MARSHITE 66.6; LAUTARITE 59

14.88 | 4.63 | -3.394 | 62.28 | 27.9

Nd — 60

Neodymium — L — UB SGP

144.27 (239.54)

			17 ?				
			23.9				
	0	18.1	0 ?		.0081		3.7
Nd 1.82	25.25	4f3-5s2-5p6-5d1-5f0-6s2				142	27.1
Nd^{+3} 1.04	4.71		.5-.38	6-8	.74	143	12.2
						144	23.9
						145	8.3
						146	17.2
						148	5.7
						150	5.6

+Pr $6.50/g — in APATITE submax THALENITE; YTTROFLUORITE submax WIIKITE; ALLANITE MONAZITE submax THORTVEITITE

87

Pm — 61

Promethium — L

[145] (240.75)

		?					
		4f4-5s2-5p6-5d1-5f0-6s2				145 ?	
Pm						~30y	K,L
Pm^{+3} 1.06	4.99		.5-.38	6-8	.76		

UNKNOWN IN NATURE ?

Ho — 67

Holmium — L — B GP

164.94 (273.86)

			1.15				
	1.2 ?			.0016		.72	
Ho 1.76	22.84	4f10-5s2-5p6-5d1-5f0-6s2				165	100
Ho^{+3} .91	3.16		.5-.38	6-8	.65		

in APATITE ? YTTROFLUORITE ? THALENITE WIIKITE XENOTIME

Er — 68

Erbium — L — B GP

167.2 (277.6)

			2.47				
	2.5 ?			.0046		2.1	
Er 1.75	22.45	4f11-5s2-5p6-5d1-5f0-6s2				162	.136
Er^{+3} .89	2.95		.5	6	.64	164	1.56
						166	33.4
						167	22.9
						168	27.1
						170	14.9

in APATITE YTTROFLUORITE THALENITE submax WIIKITE XENOTIME submax

W — 74

Tungsten — LS — 80 [7] B GP

183.92 (305.37)

					Pr	TRACE	
		1.5-69		1-2 ?		8.1	
					.041	18	
W 1.36	10.54	5d4-5f0-6s2				180	.14
W^{+4} .70	1.44		.66	6	.50	182	26.2
W^{+6} .62	1.00	61	.66-1.4	4-6	.44	183	14.3
						184	30.7
						186	28.7

$22/kg — WOLFRAMITE 60.7 HÜBNERITE 60.7; SCHEELITE 63.9 FERBERITE 60.7; STOLZITE 40.5 in COLUMBITE

201.6 | 191.6 | -140.44 | 41.55 | 8.0

Re — 75

Rhenium — S — SdB GP

186.31 (309.34)

.02			<.001	Pr as PERRHENATE		.001	
.0001	.001		<.001			.0082	
				.0002		.0008	
Re 1.38	11.01	5d5-5f0-6s2				185	37.1
Re^{+4} .72	1.56		.66	6	.51	187	62.9
Re^{+7} .56	.74	79 ?	1.8-1.2	4-6	.40		

$4/g — in MOLYBDENITE .25 in CHROMITE 10^{-6}; in GADINOLITE 10^{-4} in ZIRCON; in COLUMBATES in TANTALATES

189 | 179 | -131.2 | 45.13 | 10

Os — 76

Osmium — S — SdB G

190.2 (315.8)

						10	
						7.6	
Pr				.0032		0	
Os 1.35	10.31	5d6-5f0-6s2				184	.018
Os^{+4} .69	1.38		.66	6	.49	186	1.59
						187	1.64
						188	13.3
						189	16.1
						190	26.4
						192	41.0

$1.60/g — IRIDOSMINE OSMIRIDIUM AUROSMIRIDIUM NATIVE Os

174 | 163 | -119.5 | 45.97 | 7.8

Ir — 77

Iridium — S — SdB G

193.1 (320.6)

						.5	
						3.0	
	.001			.0010		0	
Ir 1.35	10.31	5d9				191	38.5
Ir^{+4} .68	1.32		.66	6	.49	193	61.5

$2.75/g — NATIVE Ir IRIDOSMINE; OSMIRIDIUM AUROSMIRIDIUM in CHROMITE

165 | 154 | -112.9 | 46.25 | 8.7

Pt — 78

Platinum — SC — SdB G

195.23 (324.15)

					PMO		
	.005			.0050			
Pt 1.38	11.01	5d9-5f0-6s1				190	
Pt^{+2} .80	2.14	19.3	.33	6	.57	192	
Pt^{+4} .65	1.15		.66	6	.46	194	
						195	
						196	
						198	

$2/g — NATIVE P. 100 COOPERITE 47.7; BRAGGITE 59.5 ± SPERRYLITE 56.6; NIGGLIITE 33.8 in CHROMITE

121.6 | 110.9 | -81.288 | 45.96 | 10.0

Po — 84

Polonium — L

210 (348.68)

						1×10^{-11}	
	3×10^{-10}			8×10^{-14}		3×10^{-11}	
Po 1.41	11.74	5f0-6s2-6p4				210	211m
Po^{+6} .67	1.26		1.0	6	.48	138.3d .52 α	
						212	
						3×10^{-7} s α	
						214	215
						1.64 × 10^{-4} s	1.83 10^{-3} s
						216	218
						0.16 s	3.05 m

in URANIUM MINERALS

At — 85

Astatine — LS

[210] (348.68)

		Pr					
		5f0-6s2-6p5				218	
At						1.3 s	α
At^{-7} .62	1.00		1.8-1.2	4-6	.44		

?

U — 92

Uranium — LC — B G

238.07 (395.28)

						2×10^{-8}	
	2×10^{-10}			8×10^{-8}			
U 1.38	11.01	5f3-6s2-6p6-6d1-7s2				234 .0057	
U^{+3} 1.04	4.71		.5-.38	6-8	.74	2.6×10^5 y α γ	
U^{+4} .97	3.82		.66-.5	6-8	.69	235 0.71	

$U^{238}/^{235}$ CONSTANT

1.2	6×10^{-4}	0
1.2	.3	007
1.3	.000054 ?	.1

Np — 93

Neptunium — L

[237] (393.50)

		Pr?					
		5f4-6s2-6p6-6d1-6s2				237 ?	
Np							
Np^{+3} 1.10	5.58		.38	8	.79		
Np^{+4} .95	3.59		.66-.5	6-8	.68		
Np^{+5} .88	2.95		.83		.63		

Pu — 94

Plutonium — L

[242] (401.81)

		Pr					
		5f5-6s2-6p6-6d1-7s2				239	
Pu						2.41×10^4 y α γ	
Pu^{+3} 1.08	5.28		.5-.38	6-8	.77		
Pu^{+4} .93	3.37		.66-.5	6-8	.66	?	

Am — 95

Americium — L

[243] (403.47)

		Pr?					
		5f6-6s2-6p6-6d1-7s2				?	
Am							
Am^{+3} 1.07	5.13		.5-.38	6-8	.76		
Am^{+4} .92	3.26		.66-.5	6-8	.66		

Cm — 96

Curium — L

[243] (40347)

		Pr?					
		5f7-6s2-6p6-6d1-7s2					

KEY

Element — S-SIDEROPHILE, C-CHALCOPHILE, L-LITHOPHILE, A-ATMOPHILE, B-BIOPHILE

Atomic Weight [#] — MASS OF ISOTOPE OF LONGEST HALF-LIFE

(#) Weight of one atom x 10^{-24} grams

Atom

Ions

Radii (Å) — THE ATOMIC RADII ARE HALF THE CLOSEST APPROACH OF THE ATOMS. THE IONIC RADII ARE THOSE FOR 6-FOLD COORDINATION BASED ON A RADIUS OF 1.40 FOR O^{-2} (Yb^{+2} & Eu^{+2} BASED ON 1.32 FOR O^{-2})

Volumes (cubic Å)

ROCK TYPE

BEHAVIOR DURING DIFFERENTIATION

GRAMS/TON

Abundance in igneous rocks

Non-radiogenic isotope data

Abundance in sandstone	Oceanic abundance	Abundance in meteoritic sulphide
Abundance in shale	Transfer percentage	Abundance in meteoritic iron
Abundance in limestone	Cosmic abundance	Abundance in meteoritic silicate

Electrons in Each Quantum Group — QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (59 zero throughout)

Ionization Potentials (volts)

Electrostatic Valences

Coordinations

Radius Ratios (cation/oxygen)

Isotopes NATURALLY OCCURRING — A# % relative abundance

RADIOACTIVE ISOTOPE — HALF-LIFE: s-SECONDS, m-MINUTES, h-HOURS, d-DAYS, y-YEARS — RADIATION DECAY: α-ALPHA, β⁻-NEGATIVE BETA, γ-GAMMA RAY, K-K ELECTRON CAPTURE, L-L ELECTRON CAPTURE, IT-ISOMERIC TRANSITION

Cost: retail. for pure element. (subject to change) Common, independent, geochemically significant and/or host minerals with % element contained.

Atomic Number

STANDARD HEAT OF FORMATION $\Delta H_f°$ (GAS) kg-cal/mole

STANDARD FREE ENERGY OF FORMATION $\Delta F_f°$ (GAS) kg-cal/mole

LOGARITHM OF EQUILIBRIUM CONSTANT OF FORMATION (25°C) log K_f

ENTROPY AT 25 C. $S°$ (GAS) cal/degree-mole

ENTROPY AT 25 C. $S°$ (SOLID) cal/degree-mole

ALL ABUNDANCE DATA GIVEN IN GRAMS PER METRIC TON

[1 g/ton = 1 p.p.m. = .0001% = 10^{-6} g/g]

ABBREVIATIONS

B-basaltic and/or gabbroic
ENR.-enriched
G-granitic and/or rhyolitic
GR-greisen
I-dioritic and/or granodioritic
nS-nepheline syenitic
P-pegmatitic
PMO-present in marine organisms
PPT-precipitated
Pr-present
S-syenitic
Sd-sulphide
SEDS.-sediments
U-ultrabasic

KEY

Element — S-SIDEROPHILE, C-CHALCOPHILE, L-LITHOPHILE, A-ATMOPHILE, B-BIOPHILE

Atomic Weight [#] MASS OF ISOTOPE OF LONGEST HALF-LIFE

(#) Weight of one atom x 10^{-24} grams

ROCK TYPE

BEHAVIOR DURING DIFFERENTIATION

GRAMS/TON

Abundance in igneous rocks | Abundance in sandstone | Abundance in shale | Abundance in limestone | Oceanic abundance | Transfer percentage | Cosmic abundance | Abundance in meteoritic sulphide | Abundance in meteoritic iron | Abundance in meteoritic silicate

Non-radiogenic isotope data

Atom

Ions

Radii (Å) — THE ATOMIC RADII ARE HALF THE CLOSEST APPROACH OF THE ATOMS. THE IONIC RADII ARE THOSE FOR 6-FOLD COORDINATION BASED ON A RADIUS OF 1.40 FOR O^{-2} (Yb^{+2} & Eu^{+2} BASED ON 1.32 FOR O^{-2})

Volumes (cubic Å)

Electrons in Each Quantum Group — QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)

Ionization Potentials (volts)

Electrostatic Valences

Coordinations

Radius Ratios (cation/oxygen)

Isotopes NATURALLY OCCURRING — A# — % relative abundance

RADIOACTIVE ISOTOPE — HALF-LIFE — RADIATION DECAY: α-ALPHA, β^--NEGATIVE BETA, γ-GAMMA RAY, K-K ELECTRON CAPTURE, L-L ELECTRON CAPTURE, IT-ISOMERIC TRANSITION; s-SECONDS, m-MINUTES, h-HOURS, d-DAYS, y-YEARS

Cost: retail, for pure element, (subject to change) Common, independent, geochemically significant and/or host minerals with % element contained.

Atomic Number

STANDARD HEAT OF FORMATION ΔHr° (GAS) kg-cal/mole

STANDARD FREE ENERGY OF FORMATION ΔFf° (GAS) kg-cal/mole

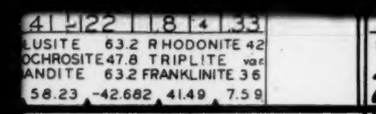
LOGARITHM OF (GAS) EQUILIBRIUM CONSTANT OF FORMATION (25°C) log Kf

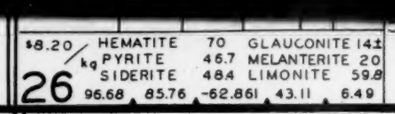
ENTROPY AT 25 C. S° (GAS) cal/degrees-mole

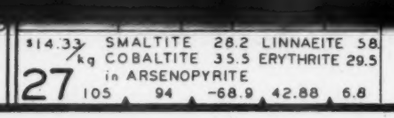
ENTROPY AT 25 C. S° (SOLID) cal/degrees-mole

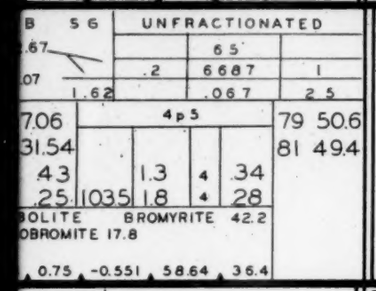
pH

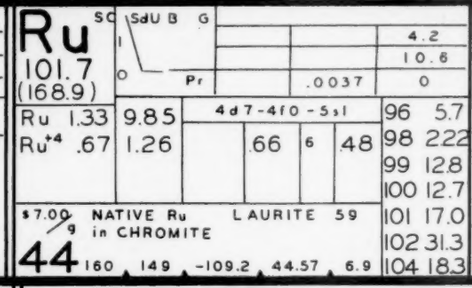
pH	PRECIPITATION OF HYDROXIDES	NATURAL MEDIA	pH
11			11
	Mg^{+2}		
10		Alkali soils	10
9	Mn^{+2}, La, Hg, Ag		9
		Sea water	
8	Ce, Co, Ni, Cd, Pr, Nd, Y		8
7	Fe^{+2}, Sm, Pb	River water	7
6	Zn^{+2}, Cu, Be, Cr^{+3}	Rain water	6
5	Al^{+3}		5
4	U^{+4}, Th^{+4}	Peat water	4
3		Mine water	3
	Fe^{+3}, Sn^{+2}, Zr^{+4}		
2			2
		Acid thermal springs	
1			1

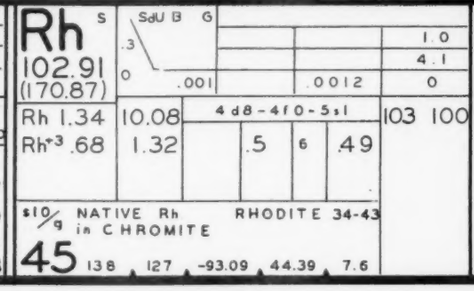


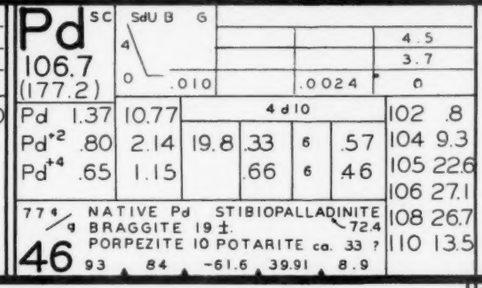


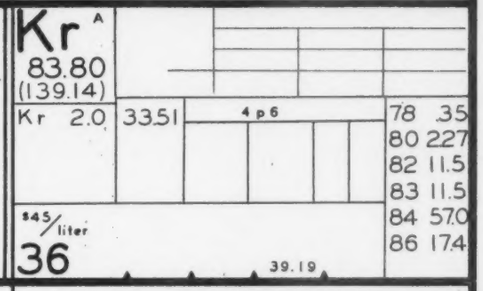


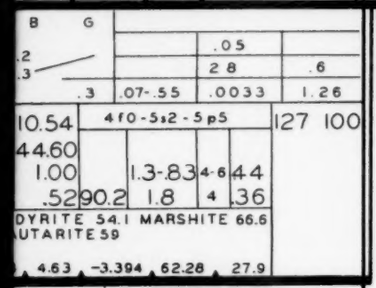


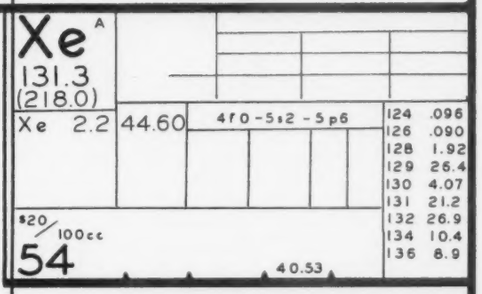


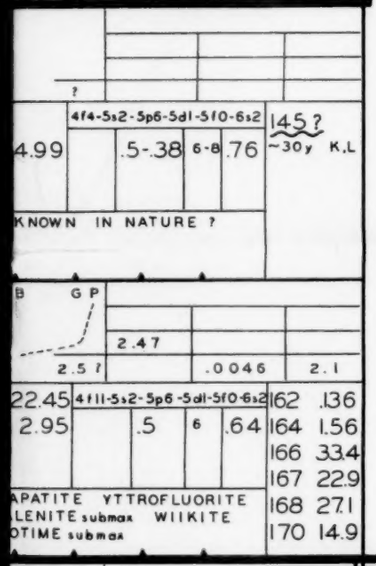


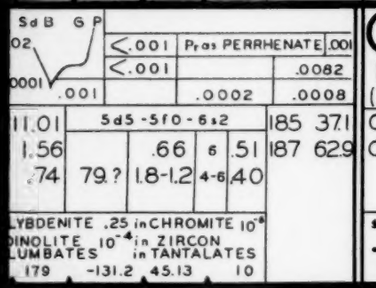


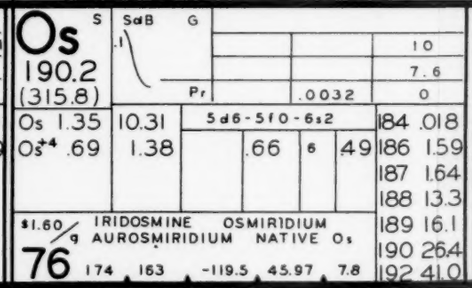


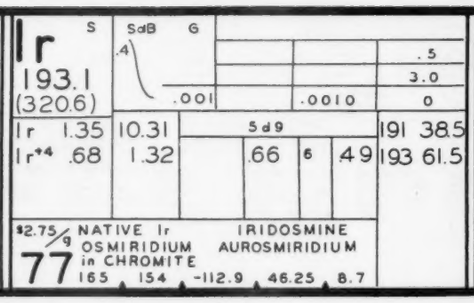


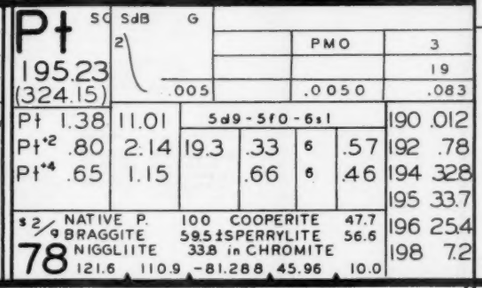


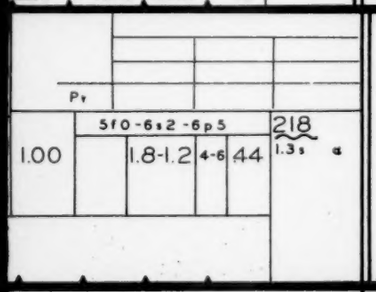


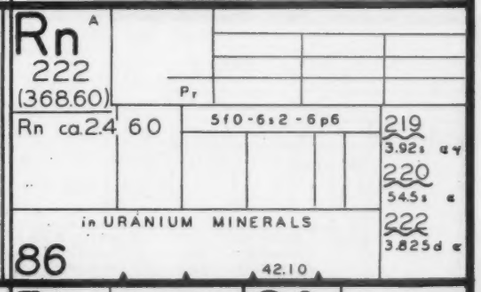


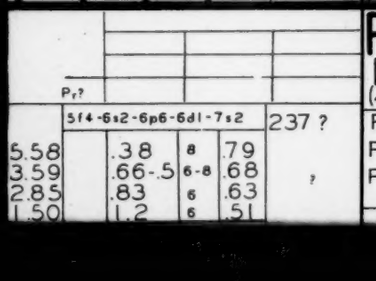


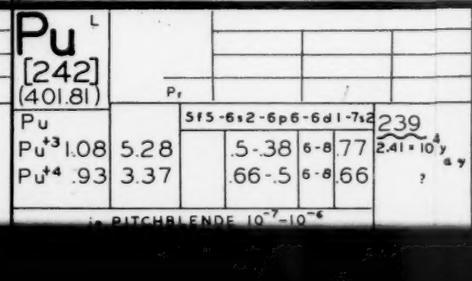


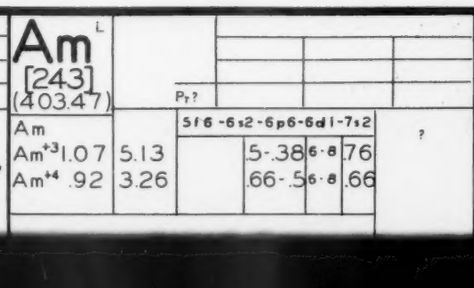


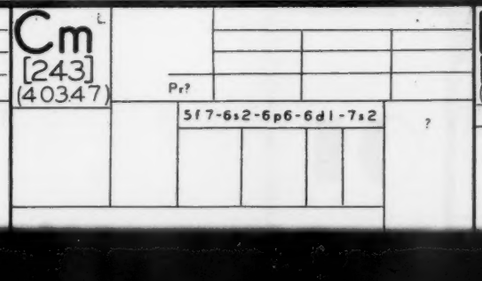


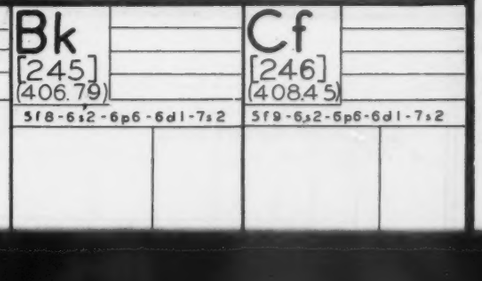










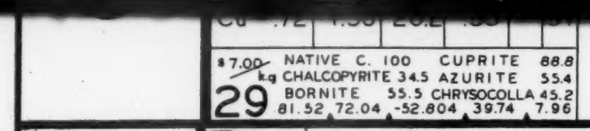


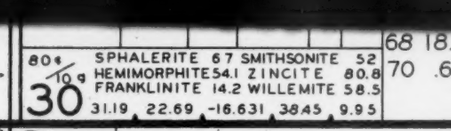
Neoytterbium-ytterbium
Neptunium Np 93
Neon Ne 10
Nickel Ni 28
Niobium Nb 41
Niton-radon
Nitrogen N 7
Osmium Os 76
Oxygen O 8
Palladium Pd 46
Phosphorus P 15
Platinum Pt 78
Plumbum-lead
Plutonium Pu 94
Polonium Po 84
Potassium K 19
Praseodymium Pr 59
Promethium Pm 61
Protactinium Pa 91
Radium Ra 88
Radium emanation-radon
Radium F-polonium
Radon Rn 86
Rhenium Re 75
Rhodium Rh 45
Rubidium Rb 37
Ruthenium Ru 44
Samarium Sm 62
Scandium Sc 21
Selenium Se 34
Silicon Si 14
Silver Ag 47
Sodium Na 11
Stannum-tin
Stibium-antimony
Strontium Sr 38
Sulfur S 16
Tantalum Ta 73
Technetium Tc 43
Tellurium Te 52
Terbium Tb 65
Thallium Tl 81
Thorium Th 90
Thulium Tm 69
Thoron-isotope of radon[220]
Tin Sn 50
Titanium Ti 22
Tritium-isotope of hydrogen[3]
Tungsten-wolfram
Uranium U 92
Vanadium V 23
Virginium-francium
Wolfram W 74
Wolframium-wolfram
Xenon Xe 54
Ytterbium Yb 70
Yttrium Y 39
Zinc Zn 30
Zirconium Zr 40

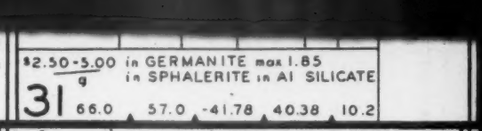
Dounds d'abondance en grammes par tonne — Gehalt-Daten in Grammen per Tonne — Soderzhanie v grammakh na tonnu — Datos de abundancia en gramos por tonelada métrica
CLEF — ZEICHENERKLÄRUNG — USLOVNIE OBOZNACHENIYA — LLAVE

Élément / Element / Element / Elemento — basaltique / basaltisch / basaltichaltig / basáltico — granitique / graniten / granitig / granítico — A G I A / B E Z B / O H O U / N A B N / D L I D / A T L A / N I C / C E I / A
Données isotopiques (non-radiogéniques) / Isotopisch Daten (nicht-radiogenisch) / Dannie ob isotopakh (ne radioaktivnikh) / Datos para los isótopos no radiogénicos
Poids atomique / Atomgewicht / Atomniy ves / Peso atómico — Conduite pendant la différentiation / Verhalten während die Differentiation / Povedenie vo vremya differentsiatsii / Conducta durante la diferenciación
Poid d'un atome / Gewicht eines Atoms / Ves odnogo atoma / Peso de un átomo (× 10⁻²⁴)
Grès / Sandstein / Peschanik / Arenisca — Argile schisteuse / Schieferton / Slantsevataya glina / Lutita — Calcaire / Kalkstein / Izvestnyak / Caliza — Rochas ígnéa / Erstarrungsgesteine / Vulkanicheskie gornie porodi / Rocas ígneas
Océan / Ozean / Okean / Océano — Transfert % / Übertrag % / Perenos % / Transborde % — Univers / Universum / Vselennaya / Cosmos
Sulfid météorique / Meteorsulfid / Meteoriy sulfid / Sulfuro meteórico — Fer météorique / Meteoreisen / Meteornoe zhelezo / Hierro meteórico — Silicat météorique / Meteorsilikat / Meteoriy silikat / Silicato meteórico

Atome / Atom / Atom / Átomo — Ions / Ionen / Ioni / Iones — Rayon (Å) / Radii / Luch / Radios
Volume (Å³) / Volumen / Ob"em / Volumenes
Électrons dans chaque groupe quantum / Elektronen in jeder Quantumgruppe / Elektroni v kazhdoy kvantovoy gruppe / Electrones en cada grupo quantum
Potentielle d'ionisation / Potentielle Ionisierung / Potentsialnaya ionizatsiya / Potencinles de ionización — Valence électrostatique / Electrostatische Valenz / Valentnost elektrostaticheskaya / Valencias electrostáticas — Coordination / Zuordnung / Koordinatsiya / Coordinaciones — Kayon / Rapport / Radius / Luch otnosheniе / Proporción de los radios
Isotope naturel / Natürliche Isotope / Estestvenniy izotop / Isótopo natural
Isotope radioactif / Radioaktive Isotope / Radioaktivniy izotop / Isótopo radioactivo
Demie-vie / Halbleben / Polovina zhiznennogo sroka / Media vida — Désintégration par radiation / Strahlungszersetzung / Raspad za schet luchеispuskaniya / Desintegración por radiación
Prix en détail pour élément pur / Kleinhandelspreis für reines Element / Roznichnaya tsena za chistiy element / Costo menudeo por elemento puro — Minéral avec % d'élément contenu / % Gehalt des Element im Mineral / Mineral s % soderzhaniya elementa / Minerales con % del elemento contenido
Nombre atomique / Atomzahl / Atomnoe chislo / Número atomico — Chaleur de combinaison / Bildungswärme / Teplota obrazovaniya / Calor de formación (gas, gas)
Énergie de formation / Bildungsenergie / Energiya obrazovaniya / Energía libre de formación — Logarithme de constante équilibre / Logarithmus der Gleichgewicht-Konstante / Logarifm postoyannoy / Logaritmo de la constante de equilibro (gas, gas)
Entropie à 25°C. / Entropie auf 25°C. / Entropiya pri 25°C / Entropía a 25°C. (gas, gas)
Entropie à 25°C. / Entropie auf 25°C. / Entropiya pri 25°C. / Entropía a 25°C. (solide, körperlich, tverdoe telo, solida)




80¢/10g SPHALERITE 67 SMITHSONITE 52
HEMIMORPHITE 54.1 ZINCITE 80.8
FRANKLINITE 14.2 WILLEMITE 58.5
30 31.19 22.69 -16.631 38.45 9.95



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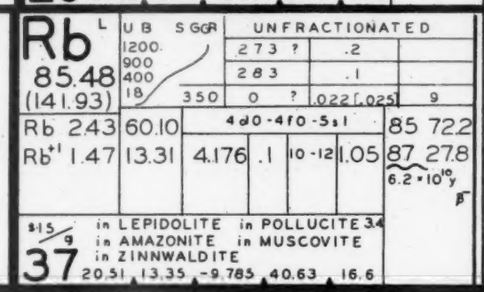

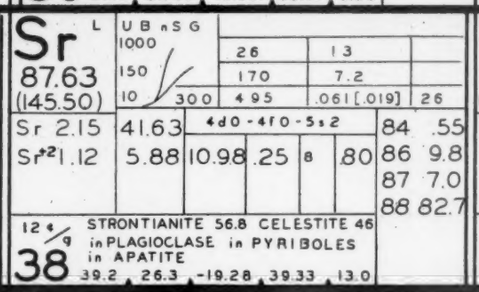

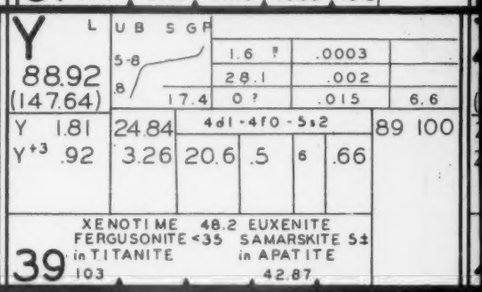

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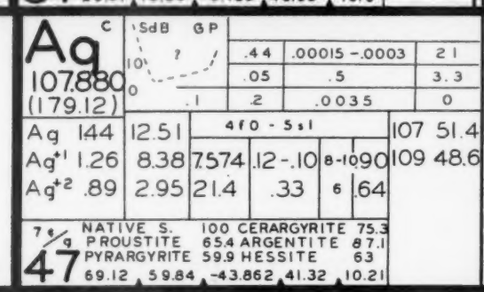

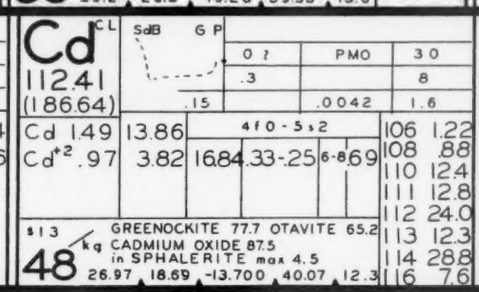

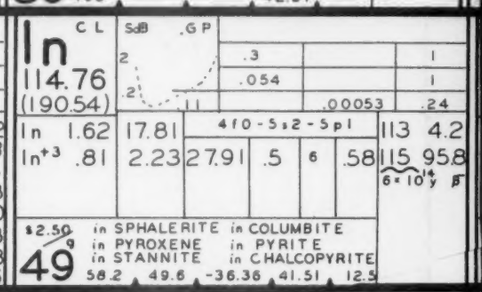

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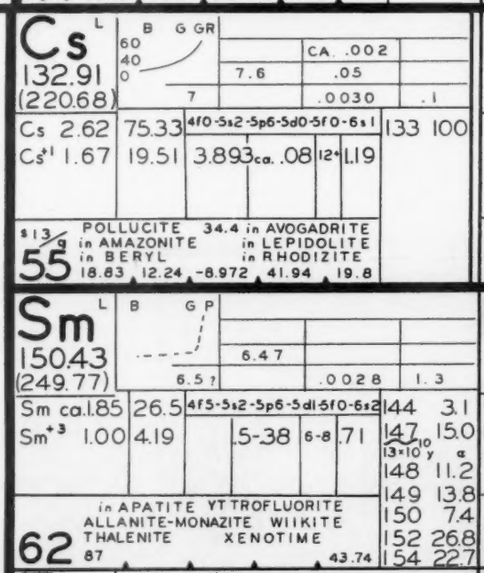
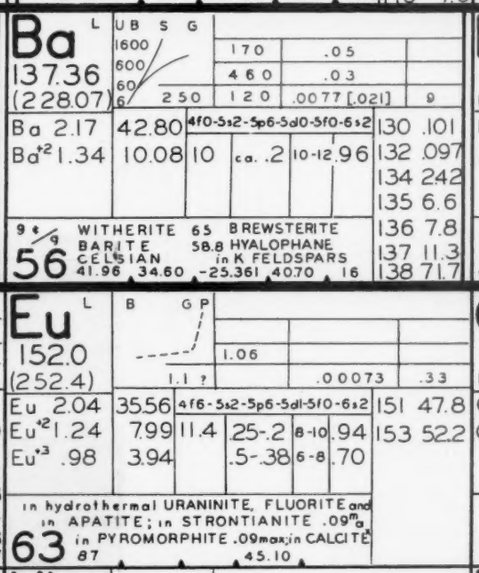
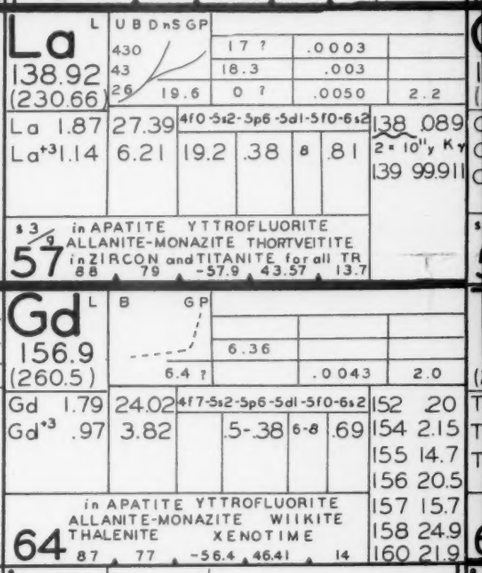
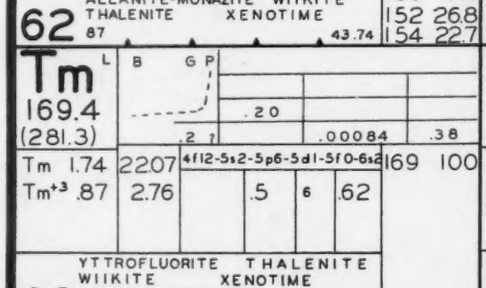
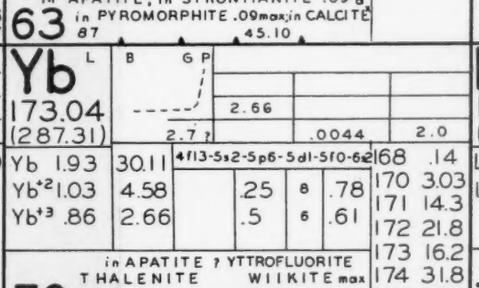
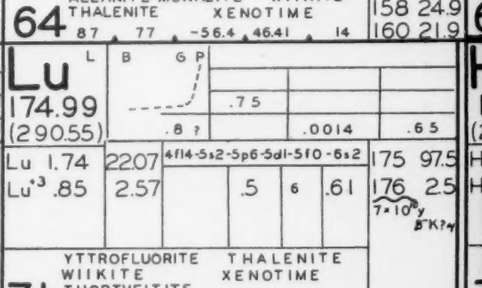


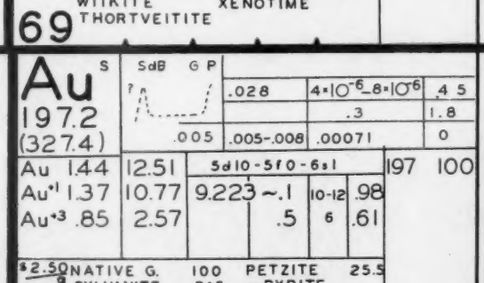


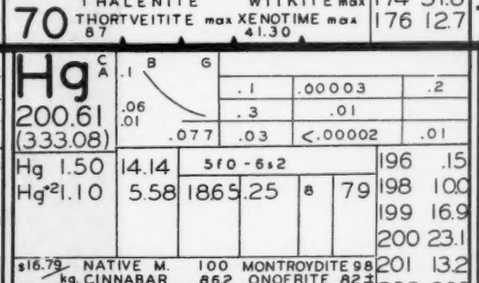


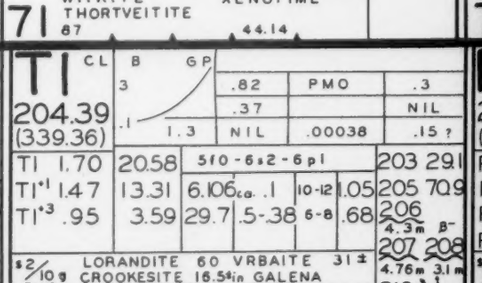



Eu L
152.0
(252.4)
B GP
1.06
1.1? .0073 .33
Eu 2.04 35.56 4f6-5s2-5p6-5d1-5f0-6s2 151 47.8
Eu+2 1.24 7.99 11.4 25-.2 8-10 .94 153 52.2
Eu+3 .98 3.94 .5-.38 6-8 .70
in hydrothermal URANINITE, FLUORITE and
in APATITE; in STRONTIANITE .09ma
63 87 in PYROMORPHITE .09max in CALCITE 45.10









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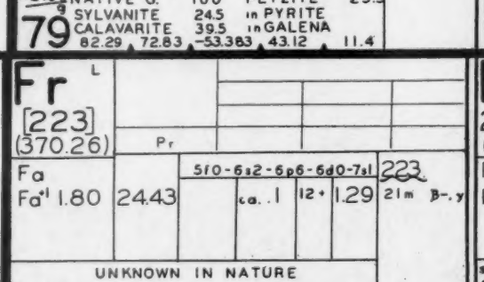

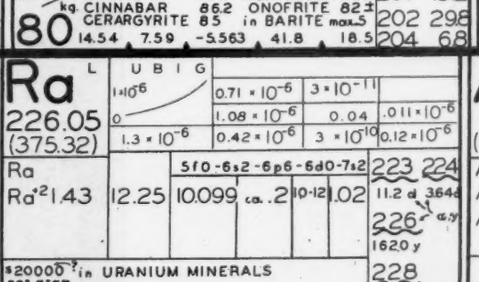

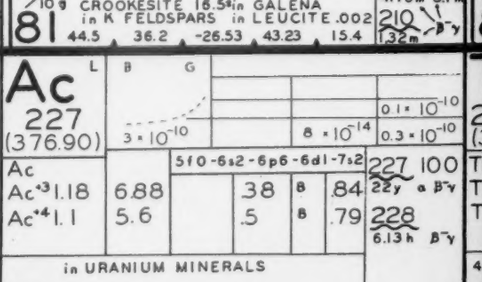

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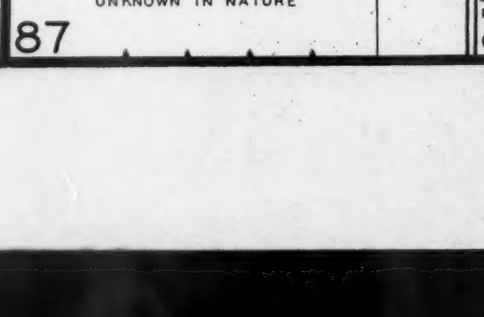

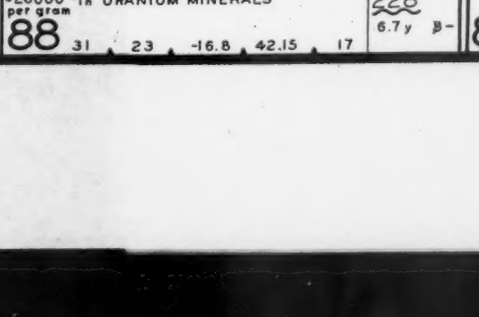

DET·PUB·LIB

31 — $2.50-5.00/g in GERMANITE max 1.85 in SPHALERITE in Al SILICATE
66.0 | 57.0 | -41.78 | 40.38 | 10.2

32 — $3.00/g ARGYRODITE 5-7 GERMANITE 10 ULTRABASITE 2.2 in SPHALERITE
78.44 | 69.50 | -50.943 | 40.11 | 10.14

33 — $5.24/kg ARSENOPYRITE 46 SMALTITE 71.8 ORPIMENT 61 COBALTITE 45.2 NICCOLITE 55.9 (gray) 8.4

34 — $29.75/kg NATIVE Se 100 in SULPHUR <5.2 GUANAJUATITE 36.2 SELENOLITE 62 TIEMANNITE 28.3 CHALCOMENITE (hex) 10.0
155.5 | 144.2 | -105.70 | 43.46 | 6.83

35 — $5.47/kg
7.3

39 — XENOTIME 48.2 EUXENITE FERGUSONITE <35 SAMARSKITE 5± in TITANITE in APATITE
103 | 42.87

40 — $15/kg ZIRCON 49.8 BADDELEYITE 74. CATAPLEITE ±23 EUDIALITE in FERROMAGNESIAN MINERALS
125 | 115 | -84.29 | 43.31 | 9.18

41 — 26¢/g COLUMBITE 57.8 MOSSITE 24± PYROCHLORE 44 ± EUXENITE 17.5± SAMARSKITE 29± in ZIRCON <1.4
184.5 | 173.7 | -127.32 | 44.49 | 8.3

42 — $11.56/kg MOLYBDENITE 60 WULFENITE 26.2 MOLYBDITE 66.7 ILSEMANNITE POWELLITE 46.5± JORDISITE 12.3
155.5 | 144.2 | -105.70 | 43.46 | 6.83

43 — ? in M

49 — $2.50/g in SPHALERITE in COLUMBITE in PYROXENE in PYRITE in STANNITE in CHALCOPYRITE
58.2 | 49.6 | -36.36 | 41.51 | 12.5

50 — $8.86/kg CASSITERITE 78.6 STANNITE 27.5 CYLINDRITE 24.8 TEALLITE 28.1 in SPHALERITE in GALENA
72 | 64 | -47.6 | 40.25 | 12.3

51 — $6.60/kg STIBNITE 71.8 NATIVE Sb 100 PYRARGYRITE 22.2 TETRAHEDRITE 24.8 SENARMONTITE 83.6 in GALENA
60.8 | 51.1 | -37.46 | 43.06 | 10.5

52 — $12.12/kg NATIVE Te 100 TELLURITE 80 CALAVERITE 56.4 SYLVANITE 64 HESSITE 37.2 TEINITE
47.6 | 38.1 | -27.93 | 43.64 | 11.88

53 — $12/kg L
14.8

57 — $3/g in APATITE YTTROFLUORITE ALLANITE-MONAZITE THORTVEITITE in ZIRCON and TITANITE for all TR
88 | 79 | -57.9 | 43.57 | 13.7

58 — $79/kg in APATITE max YTTROFLUORITE max ALLANITE-MONAZITE max WIIKITE THALENITE THORTVEITITE
85 | 13.8

59 — in APATITE YTTROFLUORITE ALLANITE-MONAZITE WIIKITE THALENITE THORTVEITITE
87

60 — +Pr in APATITE submax THALENITE $6.50/g YTTROFLUORITE submax WIIKITE ALLANITE MONAZITE submax THORTVEITITE
87

61 — UN

64 — in APATITE YTTROFLUORITE ALLANITE-MONAZITE WIIKITE THALENITE XENOTIME
87 | 77 | -56.4 | 46.41 | 14

65 — in APATITE YTTROFLUORITE THALENITE XENOTIME WIIKITE
87

66 — in APATITE YTTROFLUORITE THALENITE max WIIKITE submax XENOTIME

67 — in APATITE ? YTTROFLUORITE ? THALENITE WIIKITE XENOTIME

68 — in A THA XEN

71 — YTTROFLUORITE WIIKITE THALENITE XENOTIME THORTVEITITE
87 | 44.14

72 — in ZIRCON in THORTVEITITE in BADDELEYITE
44.65 | 13.1

73 — $110/kg TANTALITE 70.6 MICROLITE 60± TAPIOLITE 78 ± FERGUSONITE <44 in TITANITE <.1 in ZIRCON
185 | 175 | -128.3 | 44.24 | 9.9

74 — $22/kg WOLFRAMITE 60.7 HUBNERITE 60.7 SCHEELITE 63.9 FERBERITE 60.7 STOLZITE 40.5 in COLUMBITE
201.6 | 191.6 | -140.44 | 41.55 | 8.0

75 — $4/g in MO in GAD in CO
189

81 — $2/10g LORANDITE 60 VRBAITE 31± CROOKESITE 16.5± in GALENA in K FELDSPARS in LEUCITE .002
44.5 | 36.2 | -26.53 | 43.23 | 15.4

82 — $3.55/kg GALENA 86.6 PYROMORPHITE 76± CERUSSITE 77.7 ANGLESITE 73.5 CROCOITE 64.1 WULFENITE 56.5
46.34 | 38.47 | -28.198 | 41.89 | 15.51

83 — $12.57/kg BISMUTHINITE 40.6 NATIVE B. 100 GUANAJUATITE 63.8
49.7 | 40.4 | -29.61 | 44.67 | 13.6

84 — in URANIUM MINERALS

85

89 — in URANIUM MINERALS

90 — 40¢/g in MONAZITE 7.9 THORITE 41± PYROCHLORE THORIANITE 66 in ALLANITE in ZIRCONS
13.6

91 — in URANIUM MINERALS

92 — $.120/kg URANINITE 88.2 CARNOTITE 54± AUTUNITE 47 ± TORBERNITE 49± URANOPHANE 56.6 BETAFITE <24
125 | 12.03

93

GEOCHEMICAL TABLE OF THE ELEMENTS FOR 1953

nS-nepheline syenitic P-pegmatitic SEDS.-sediments U-ultrabasic

34 — [illegible]

$ /kg GUANAJUATITE 36.2 SELENOLITE 62 TIEMANNITE 28.3 CHALCOMENITE (hex) 10.0

								80	49.9
								82	9.0

35 — IODOBROMITE 17.8

$ /kg

7.34 | 0.75 | -0.551 | 58.64 | 36.4

Mo — 95.95 (159.31) — 42

SC | B | G

					.0003-.0007			11	
					.008			16.6	
					.0097			2.5	
Mo 1.36	10.54	4d5-4f0-5s1						92	15.7
Mo+4 .70	1.44			.66	6	.50		94	9.3
Mo+6 .62	1.00	70		1.5-1.0	4-6	.44		95	15.7
								96	16.5
								97	9.5
								98	23.8
								100	9.5

$11.56/kg MOLYBDENITE 60 WULFENITE 26.2 MOLYBDITE 66.7 ILSEMANNITE POWELLITE 46.5± JORDISITE 12.3

155.5 | 144.2 | -105.70 | 43.46 | 6.83

Tc — [99] (164.38) — 43

SC

Tc		4d6-4f0-5s1					99 ?	
Tc+7 .56	.74	95 ?		1.8-1.2	4-6	.40	2.1×10^5 y β⁻	

? in MOLYBDENITE ?

9

Ru — 101.7 (168.9) — 44

SC | SdU B G | Pr

							4.2		
							10.6		
					.0037		0		
Ru 1.33	9.85	4d7-4f0-5s1						96	5.7
Ru+4 .67	1.26			.66	6	.48		98	222
								99	12.8
								100	12.7
								101	17.0
								102	31.3
								104	18.3

$7.00/g NATIVE Ru LAURITE 59 in CHROMITE

160 | 149 | -109.2 | 44.57 | 6.9

Rh — 102.91 (170.87) — 45

S | SdU B G

							1.0		
							4.1		
					.0012		0		
Rh 1.34	10.08	4d8-4f0-5s1						103	100
Rh+3 .68	1.32			.5	6	.49			

$10/g NATIVE Rh RHODITE 34-43 in CHROMITE

138 | 127 | -93.09 | 44.39 | 7.6

Pd — 106.7 (177.2) — 46

SC | SdU B G

							4.5		
							3.7		
					.0024		0		
Pd 1.37	10.77	4d10						102	.8
Pd+2 .80	2.14	19.8		.33	6	.57		104	9.3
Pd+4 .65	1.15			.66	6	.46		105	22.6
								106	27.1
								108	26.7
								110	13.5

774/g NATIVE Pd STIBIOPALLADINITE 72.4 BRAGGITE 19 ± PORPEZITE 10 POTARITE ca. 33 ?

93 | 84 | -61.6 | 39.91 | 8.9

Te — 127.61 (211.88) — 52

C | SdB | G P

							1.7		
	.0018 ?			.00035			chondrite .13		
Te 1.43	12.25	4f0-5s2-5p4						120	.091
Te-2 2.11	39.35							122	2.5
Te+4 .70	1.44	37.7		.66	6	.50		123	.88
Te+6 .56	.74	72.0		1.5-1.0	4-6	.40		124	4.6
								125	7.0
								126	18.7
								128	31.8
								130	34.4

$12.12/kg NATIVE Te 100 TELLURITE 80 CALAVERITE 56.4 SYLVANITE 64 HESSITE 37.2 TEINITE

47.6 | 38.1 | -27.93 | 43.64 | 11.88

I — 126.91 (210.72) — 53

L A B | B G

							.05		
							2.8		.6
	.3	.07-.55		.0033			1.26		
I 1.36	10.54	4f0-5s2-5p5						127	100
I-1 2.20	44.60								
I+5 .62	1.00			1.3-.83	4-6	.44			
I+7 .50	.52	90.2		1.8	4	.36			

$12/kg IODYRITE 54.1 MARSHITE 66.6 LAUTARITE 59

14.88 | 4.63 | -3.394 | 62.28 | 27.9

Nd — 144.27 (239.54) — 60

L | UB | SGP

			17 ?						
			23.9						
	18.1		0 ?		.0081		3.7		
Nd 1.82	25.25	4f3-5s2-5p6-5d1-5f0-6s2						142	27.1
Nd+3 1.04	4.71			.5-.38	6-8	.74		143	12.2
								144	23.9
								145	8.3
								146	17.2
								148	5.7
								150	5.6

+Pr in APATITE submax THALENITE $6.50/g YTTROFLUORITE submax WIIKITE ALLANITE MONAZITE sub max THORTVEITITE

87

Pm — [145] (240.75) — 61

L

	?							
Pm		4f4-5s2-5p6-5d1-5f0-6s2					145 ?	
Pm+3 1.06	4.99			.5-.38	6-8	.76	~30y K,L	

UNKNOWN IN NATURE ?

Ho — 164.94 (273.86) — 67

L | B | GP

			1.15						
	1.2 ?				.0016		.72		
Ho 1.76	22.84	4f10-5s2-5p6-5d1-5f0-6s2						165	100
Ho+3 .91	3.16			.5-.38	6-8	.65			

in APATITE ? YTTROFLUORITE ? THALENITE WIIKITE XENOTIME

Er — 167.2 (277.6) — 68

L | B | GP

			2.47						
	2.5 ?				.0046		2.1		
Er 1.75	22.45	4f11-5s2-5p6-5d1-5f0-6s2						162	.136
Er+3 .89	2.95			.5	6	.64		164	1.56
								166	33.4
								167	22.9
								168	27.1
								170	14.9

in APATITE YTTROFLUORITE THALENITE submax WIIKITE XENOTIME submax

KEY

Element	S-SIDEROPHILE C-CHALCOPHILE L-LITHOPHILE A-ATMOPHILE B-BIOPHILE	ROCK TYPE	Non-radiogenic isotope data		
Atomic Weight [#] MASS OF ISOTOPE OF LONGEST HALF-LIFE		BEHAVIOR DURING DIFFERENTIATION	Abundance in sandstone	Oceanic abundance	Abundance in meteoritic sulphide
		GRAMS/TON	Abundance in shale	Transfer percentage	Abundance in meteoritic iron
(#) Weight of one atom x 10^{-24} grams		Abundance in igneous rocks	Abundance in limestone	Cosmic abundance	Abundance in meteoritic silicate

Atom / Ions	Radii (Å)	Volumes (cubic Å)	Electrons in Each Quantum Group				Isotopes NATURALLY OCCURRING
			Ionization Potentials (volts)	Electrostatic Valences	Coordinations	Radius Ratios cation/oxygen	A# % relative abundance

THE ATOMIC RADII ARE HALF THE CLOSEST APPROACH OF THE ATOMS. THE IONIC RADII ARE THOSE FOR 6-FOLD COORDINATION BASED ON A RADIUS OF 1.40 FOR O^{-2} (Yb^{+2} & Eu^{+2} BASED ON 1.32 FOR O^{-2})

QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)

Cost: retail, for pure element, (subject to change) Common, independent, geochemically significant and/or host minerals with % element contained.

Atomic Number	STANDARD HEAT OF FORMATION ΔHf° (GAS) kg-cal/mole	STANDARD FREE ENERGY OF FORMATION ΔFf° (GAS) kg-cal/mole	LOGARITHM (GAS) OF EQUILIBRIUM CONSTANT OF FORMATION (25°C) log Kf	ENTROPY AT 25 C. S° (GAS) cal/degree-mole	ENTROPY AT 25 C. S° (SOLID) cal/degree-mole

RADIOACTIVE ISOTOPE

HALF-LIFE: s - SECONDS; m - MINUTES; h - HOURS; d - DAYS; y - YEARS

RADIATION DECAY: α - ALPHA; β⁻ - NEGATIVE BETA; γ - GAMMA RAY; K-K ELECTRON CAPTURE; L-L ELECTRON CAPTURE; IT-ISOMERIC TRANSITION

W — 183.92 (305.37) — 74

LS | [7] | B | GP

						Pr	TRACE		
			1-2 ?				8.1		
	1.5-69				.041		18		
W 1.36	10.54	5d4-5f0-6s2						180	.14
W+4 .70	1.44			.66	6	.50		182	26.2
W+6 .62	1.00	61		.66-1.	4-6	.44		183	14.3
								184	30.7
								186	28.7

$22/kg WOLFRAMITE 60.7 HUBNERITE 60.7 SCHEELITE 63.9 FERBERITE 60.7 STOLZITE 40.5 in COLUMBITE

201.6 | 191.6 | -140.44 | 41.55 | 8.0

Re — 186.31 (309.34) — 75

S | SdB | G P | Pr as PERRHENATE

	.02			<.001			.001		
	.0001		.001	<.001			.0082		
					.0002		.0008		
Re 1.38	11.01	5d5-5f0-6s2						185	37.1
Re+4 .72	1.56			.66	6	.51		187	62.9
Re+7 .56	.74	79 ?		1.8-1.2	4-6	.40			

$4/g in MOLYBDENITE .25 in CHROMITE 10^{-6} in GADINOLITE 10^{-4} in ZIRCON in COLUMBATES in TANTALATES

189 | 179 | -131.2 | 45.13 | 10

Os — 190.2 (315.8) — 76

S | SdB | G | Pr

							10		
							7.6		
					.0032		0		
Os 1.35	10.31	5d6-5f0-6s2						184	.018
Os+4 .69	1.38			.66	6	.49		186	1.59
								187	1.64
								188	13.3
								189	16.1
								190	26.4
								192	41.0

$1.60/g IRIDOSMINE OSMIRIDIUM AUROSMIRIDIUM NATIVE Os

174 | 163 | -119.5 | 45.97 | 7.8

Ir — 193.1 (320.6) — 77

S | SdB | G | Pr

							.5		
							3.0		
	.001				.0010		0		
Ir 1.35	10.31	5d9						191	38.5
Ir+4 .68	1.32			.66	6	.49		193	61.5

$2.75/g NATIVE Ir IRIDOSMINE OSMIRIDIUM AUROSMIRIDIUM in CHROMITE

165 | 154 | -112.9 | 46.25 | 8.7

Pt — 195.23 (324.15) — 78

SC | SdB | G

					PMO		3		
							19		
	.005				.0050		.083		
Pt 1.38	11.01	5d9-5f0-6s1						190	.012
Pt+2 .80	2.14	19.3		.33	6	.57		192	.78
Pt+4 .65	1.15			.66	6	.46		194	32.8
								195	33.7
								196	25.4
								198	7.2

$2/g NATIVE P. 100 COOPERITE 47.7 BRAGGITE 59.5 ±SPERRYLITE 56.6 NIGGLIITE 33.8 in CHROMITE

121.6 | 110.9 | -81.288 | 45.96 | 10.0

Po — 210 (348.68) — 84

L

							1×10⁻¹¹		
	3×10⁻¹⁰			8×10⁻¹⁴			3×10⁻¹¹		
Po 1.41	11.74	5f0-6s2-6p4						210	211m
Po+6 .67	1.26			1.0	6	.48		138.3d .52α	52s
								212 3×10⁻⁷s α	
								214	215
								1.64×10⁻⁴	1.83×10⁻³s
								216	218
								0.16s α	3.05m β⁻

in URANIUM MINERALS

At — [210] (348.68) — 85

LS

	Pr							
At		5f0-6s2-6p5					218	
At+7 .62	1.00			1.8-1.2	4-6	.44	1.3s α	

?

U — 238.07 (395.28) — 92

LC | B | G

U 238/235 CONSTANT

			1.2	6×10⁻⁴			0		
			1.2	.3			.007		
			1.3	.000054 ?			.1		
U 1.38	11.01	5f3-6s2-6p6-6d1-7s2						234	.0057
U+3 1.04	4.71			.5-.38	6-8	.74		2.6×10⁵y α γ	
U+4 .97	3.82			.66-.5	6-8	.69		235	0.71
U+6 .80	2.14			1.0	6	.57		7.1×10⁸y α γ	
								238	99.28
								4.5×10⁹y α γ	

$120/kg URANINITE 88.2 CARNOTITE 54± AUTUNITE 47± TORBERNITE 49± URANOPHANE 56.6 BETAFITE <24

125 | 12.03

Np — [237] (393.50) — 93

L

	Pr?							
Np		5f4-6s2-6p6-6d1-7s2					237 ?	
Np+3 1.10	5.58			.38	8	.79		
Np+4 .95	3.59			.66-.5	6-8	.68		
Np+5 .88	2.85			.83	6	.63		
Np+7 .71	1.50			1.2	6	.51		

?

Pu — [242] (401.81) — 94

L

	Pr							
Pu		5f5-6s2-6p6-6d1-7s2					239	
Pu+3 1.08	5.28			.5-.38	6-8	.77	2.41×10⁴y α γ	
Pu+4 .93	3.37			.66-.5	6-8	.66		

in PITCHBLENDE 10^{-7}–10^{-6}

?

Am — [243] (403.47) — 95

L

	Pr?							
Am		5f6-6s2-6p6-6d1-7s2						
Am+3 1.07	5.13			.5-.38	6-8	.76		
Am+4 .92	3.26			.66-.5	6-8	.66		

?

Cm — [243] (403.47) — 96

L

	Pr?							
		5f7-6s2-6p6-6d1-7s2						

?

TABLE OF THE ELEMENTS FOR 1953

ENR.-enriched
G-granitic and/or rhyolitic
GR-greisen
I-dioritic and/or granodioritic
nS-nepheline syenitic
P-pegmatitic
PP-precipitated
Pr-present
S-syenitic
Sd-sulphide
SEDS.-sediments
U-ultrabasic

KEY

Element	S-SIDEROPHILE, C-CHALCOPHILE, L-LITHOPHILE, A-ATMOPHILE, B-BIOPHILE
Atomic Weight [#]	MASS OF ISOTOPE OF LONGEST HALF-LIFE
(#) Weight of one atom x 10^{-24} grams	
Atom Ions Radii (Å)	THE ATOMIC RADII ARE HALF THE CLOSEST APPROACH OF THE ATOMS. THE IONIC RADII ARE THOSE FOR 6-FOLD COORDINATION BASED ON A RADIUS OF 1.40 FOR O^{-2} (Yb^{+2} & Eu^{+2} BASED ON 1.32 FOR O^{-2})
ROCK TYPE BEHAVIOR DURING DIFFERENTIATION	GRAMS/TON
Abundance in igneous rocks	Abundance in sandstone / Abundance in shale / Abundance in limestone
Oceanic abundance / Transfer percentage / Cosmic abundance	Abundance in meteoritic sulphide / Abundance in meteoritic iron / Abundance in meteoritic silicate
Volumes (cubic Å)	
Electrons in Each Quantum Group	QUANTUM GROUPS 1s thru 7s CORRESPOND TO SHELLS K thru Q; QUANTUM GROUPS FILLED BEFORE 1st GROUP LISTED AND EMPTY AFTER LAST GROUP LISTED (5g zero throughout)
Ionization Potentials (volts)	
Electrostatic Valences	
Coordinations	
Radius Ratios (cation/oxygen)	
Isotopes NATURALLY OCCURRING A# % relative abundance	
Cost: retail, for pure element, (subject to change)	Common, independent, geochemically significant and/or host minerals with % element contained.
Atomic Number	STANDARD HEAT OF FORMATION $\Delta H_f°$ (GAS) kg-cal/mole; STANDARD FREE ENERGY OF FORMATION $\Delta F_f°$ (GAS) kg-cal/mole; LOGARITHM OF EQUILIBRIUM CONSTANT OF FORMATION (25°C) log Kf; ENTROPY AT 25 C. $S°$ (GAS) cal/degree-mole; ENTROPY AT 25 C. $S°$ (SOLID) cal/degree-mole

RADIOACTIVE ISOTOPE: HALF-LIFE (s-SECONDS, m-MINUTES, h-HOURS, d-DAYS, y-YEARS); RADIATION DECAY (α-ALPHA, β⁻-NEGATIVE BETA, γ-GAMMA RAY, K-K ELECTRON CAPTURE, L-L ELECTRON CAPTURE, IT-ISOMERIC TRANSITION)

Ru 44
101.7 (168.9) SC
SdU B G
Ru 1.33 | 9.85 | 4d7-4f0-5s1 | .66 | 6 | .48
Ru^{+4} .67 | 1.26
$7.00/g NATIVE Ru LAURITE 59 in CHROMITE
160 149 -109.2 44.57 6.9
4.2 / 10.6 / 0
96 5.7 | 98 222 | 99 128 | 100 12.7 | 101 17.0 | 102 31.3 | 104 18.3

Rh 45
102.91 (170.87) S
SdU B G
Rh 1.34 | 10.08 | 4d8-4f0-5s1 | 103 100
Rh^{+3} .68 | 1.32 | .5 | 6 | .49
$10/g NATIVE Rh RHODITE 34-43 in CHROMITE
138 127 -93.09 44.39 7.6
1.0 / 4.1 / 0

Pd 46
106.7 (177.2) SC
SdU B G
Pd 1.37 | 10.77 | 4d10 | 102 .8
Pd^{+2} .80 | 2.14 | 19.8 | .33 | 6 | .57 | 104 9.3
Pd^{+4} .65 | 1.15 | .66 | 6 | .46 | 105 22.6 | 106 27.1 | 108 26.7 | 110 13.5
774/g NATIVE Pd STIBIOPALLADINITE 72.4 BRAGGITE 19± PORPEZITE 10 POTARITE ca. 33 ?
93 84 -61.6 39.91 8.9
4.5 / 3.7 / 0

Xe 54
131.3 (218.0) A
Xe 2.2 | 44.60 | 4f0-5s2-5p6 | 124 .096 | 126 .090 | 128 1.92 | 129 26.4 | 130 4.07 | 131 21.2 | 132 26.9 | 134 10.4 | 136 8.9
$20/100cc
40.53

Os 76
190.2 (315.8) S
SdB G
Os 1.35 | 10.31 | 5d6-5f0-6s2 | .66 | 6 | .49
Os^{+4} .69 | 1.38
$1.60/g IRIDOSMINE OSMIRIDIUM AUROSMIRIDIUM NATIVE Os
174 163 -119.5 45.97 7.8
10 / 7.6 / 0
184 .018 | 186 1.59 | 187 1.64 | 188 13.3 | 189 16.1 | 190 26.4 | 192 41.0

Ir 77
193.1 (320.6) S
SdB G
Ir 1.35 | 10.31 | 5d9 | 191 38.5
Ir^{+4} .68 | 1.32 | .66 | 6 | .49 | 193 61.5
$2.75/g NATIVE Ir OSMIRIDIUM in CHROMITE IRIDOSMINE AUROSMIRIDIUM
165 154 -112.9 46.25 8.7
.5 / 3.0 / 0

Pt 78
195.23 (324.15) SC
SdB G
Pt 1.38 | 11.01 | 5d9-5f0-6s1 | 190 .012
Pt^{+2} .80 | 2.14 | 19.3 | .33 | 6 | .57 | 192 .78
Pt^{+4} .65 | 1.15 | .66 | 6 | .46 | 194 32.8 | 195 33.7 | 196 25.4 | 198 7.2
$2/g NATIVE P. 100 COOPERITE 47.7 BRAGGITE 59.5 ± SPERRYLITE 56.6 NIGGLIITE 33.8 in CHROMITE
121.6 110.9 -81.288 45.96 10.0
PMO / 3 / 19
.005 .0050 .083

Rn 86
222 (368.60) A
Rn ca.2.4 | 60 | 5f0-6s2-6p6 | 219 3.92s αγ | 220 54.5s α | 222 3.825d α
in URANIUM MINERALS
42.10

Pu 94
[242] (401.81) L
Pu | 5f5-6s2-6p6-6d1-7s2 | 239
Pu^{+3} 1.08 | 5.28 | .5-.38 | 6-8 | .77 | 2.41×10⁴ y α γ
Pu^{+4} .93 | 3.37 | .66-.5 | 6-8 | .66
in PITCHBLENDE 10^{-7}-10^{-6}

Am 95
[243] (403.47) L
Am | 5f6-6s2-6p6-6d1-7s2
Am^{+3} 1.07 | 5.13 | .5-.38 | 6-8 | .76
Am^{+4} .92 | 3.26 | .66-.5 | 6-8 | .66

Cm 96
[243] (403.47) L
5f7-6s2-6p6-6d1-7s2

Bk 97
[245] (406.79)
5f8-6s2-6p6-6d1-7s2

Cf 98
[246] (408.45)
5f9-6s2-6p6-6d1-7s2

pH

pH	PRECIPITATION OF HYDROXIDES	NATURAL MEDIA	pH
11			11
	Mg^{+2}		
10		Alkali soils	10
9			9
	Mn^{+2}, La, Hg, Ag		
		Sea water	
8	Ce, Co, Ni, Cd, Pr, Nd, Y		8
7	Fe^{+2}, Sm, Pb	River water	7
6	Zn^{+2}, Cu, Be, Cr^{+3}	Rain water	6
5	Al^{+3}		5
4	U^{+4}, Th^{+4}	Peat water	4
3		Mine water	3
	Fe^{+3}, Sn^{+2}, Zr^{+4}		
2			2
		Acid thermal springs	
1			1

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Chart 8b.- CORRELATION OF THE TRIASSIC FORMATIONS OF CANADA

By Frank H. McLearn

WESTERN CORDILLERA

		Queen Charlotte Islands		Vancouver Island					Queen Charlotte Strait to Strait of Georgia			Yukon		Northern British Columbia					Southern British Columbia									North
		Graham Island	Section Cove	Quatsino Sound	Nimpkish, Zeballos Inlet	Kyuquot Sound to Esperanza Inlet	Buttle Lake	Cowichan Lake	Swanson, Harbledown Islands	Open Bay, Quadra Island	Texada Island	Beaver and Rocky Rivers	Southern Yukon	Taku River	Dease River	Lower Stikine	McConnell Creek, Aiken Lake, Fort St James area	Zymoetz River	Whitesail Lake area	Mount Kappan, Klinaklini River, Homathko River	Chilko, Taseko Lakes	Bridge River district (Tyaughton Creek)	Southwest part Hope Sheet	Ashcroft, Nicola, Princeton areas	Hedley (Princeton area)	Slocan and Sandon areas	Salmo, Ymir areas	Liard and West
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
Overlying beds		Maude (Jurassic)	Jurassic argillites and limestones	Jurassic	Bonanza group (Jurassic)	Bonanza group (Jurassic)	Jurassic?	?	Harbledown fm. (Jurassic)	?	Cretaceous	?	Laberge group (Jurassic)	Takwahoni group (Jurassic)	McLeod group (Jurassic)	Jurassic	Takla group (Jurassic)	Hazelton group (Jurassic)	Hazelton group (Jurassic)	Jurassic	Coast Range batholith	Lower Jurassic	Cultus ? formation	Jurassic	?	Nelson gneiss	Hall group (Jurassic)	Garbutt (Jurassic)
TRIASSIC Upper	Rhaetian																											
	Norian	"Maude" formation	Argillites and limestone	Sediments and Volcanic rocks	Bonanza group (part)	Bonanza group (part) Thin-bedded member; Arenaceous member	Limestones and argillites	Vancouver volcanics: Sutton Is. member	Parson Bay formation		Marble Bay formation	Limestones and argillites	Lewes River group	Honakta fm.	Limestone (Thibert?)	Sedimentary group	Takla group	Limestones, argillites, breccias, tuffs	Argillaceous sediments, tuffs, breccias	Volcanic and sedimentary rocks	Volcanic and sedimentary rocks	Tyaughton (Hurley) group; Pioneer fm.; Noel fm.	Cultus ? formation	Nicola (Tulameen) group	Wolfe Creek fm.; Henry fm.; Hedley fm.; Sunnyside Is.; Redtop fm.	Slocan group; Kaslo gr.; Milford gr.	Elise formation; Ymir group	Liard formation
	Karnian		Greenstones	Quatsino Is.; Volcanic rocks and sediments	Quatsino Is.; Karmutsen volcanics	Quatsino Is.; Karmutsen volcanics	Volcanic beds		Valdes formation	Argillaceous Is. and volcanic rocks; Valdes volcanics	Texada formation			Stuhini group; King Salmon group		Volcanic group												
Middle	Ladinian																											
	Anisian																											Toad formation
Lower																												Grayling formation
Underlying beds		?	?	?	?	?	Permian	Paleozic	?	?	Anderson Bay (Late Paleozoic)	?	Late Paleozoic	Permian	Dease group (Permian)	Permian	Late Paleozoic	Permian	?	?	?	Fergusen group (Late Paleozoic)	?	Permian	?	Milford (Late Paleozoic)	Seaman group	P
References to Bibliography		37, 89	37	40	52, 54, 55, 56	69	53	25, 26, 29	8, 30	8, 90	86, 90, 99	71	13, 28, 84, 85	74	62, 72	75	5, 6, 7, 88, 117	58	S. Duffell, H.W. Tipper (oral communication)	43	42	18, 70	31, 34	27, 32, 36, 48, 115	12	16	87	76, 77, 92

IASSIC FORMATIONS OF CANADA

McLearn

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*

	Southern British Columbia						EASTERN CORDILLERA: Northeastern British Columbia			EASTERN CORDILLERA: Athabasca to Wapiti River			GREAT PLAINS	CANADIAN ARCTIC	APPALACHIAN REGION		
	Chilko, Taseko Lakes	Bridge River district (Tyaughton Creek)	Southwest part Hope Sheet	Ashcroft, Nicola, Princeton areas	Hedley (Princeton area)	Slocan and Sandon areas	Salmo, Ymir areas	Liard and Tetsa Valleys: West	Liard and Tetsa Valleys: East	Sikanni Chief and Halfway Valleys	Peace River Foothills	Mountains: Mowitch Creek	Mountains: Vine Creek	Foothills: Entrance, Moon Crk. areas	Bow River to Athabasca River	Bonanza Well, Northwestern Alberta	Axel Heiberg and Ellesmere Islands	Quaco (St. Martin's) N. B.	North Mountain, Annapolis – Cornwallis Valley and Minas basin, N. S.	
	20	21	22	23	24	25	26	27		28	29	30	31	32	33	34	35	36	37	
	st Range batholith	Lower Jurassic	Cultus ? (Jurassic part)	Jurassic	?	Nelson gneiss	Hall group (Jurassic)	Garbutt (Jurassic or L. Cretaceous)		Fernie (Jurassic)	Fernie (Jurassic)	Fernie (Jurassic)	Fernie (Jurassic)	Fernie (Jurassic)	Fernie (Jurassic)	Fernie (Jurassic)	?	?	?	Overlying beds
	canic and dimentary rocks	Tyaughton (Hurley) group	Cultus ? formation	Nicola (Tulameen) group	Wolfe Creek fm.		Elise formation			Pardonet beds	Pardonet beds		Monotis beds							Rhaetian
		Pioneer fm.			Henry fm.															Norian
					Hedley fm.															
		Noel fm.			Sunnyside ls.															
					Redtop fm.	Slocan group	Ymir group					Gray limestone, sandstone				Gray limestones, calcareous siltstones, etc.	Sandstone, shale, limestone		Scots Bay fm.	Karnian
						Kaslo gr.													North Mountain basalt	
						Milford gr.				"Gray beds"	"Gray beds"	Yellow, buff weathering shales							Blomidon shale	
								Liard formation		"Dark siltstones"	"Dark siltstones"	"Red beds", gypsum				"Red beds"		Upper Red sandstone	Wolfville sandstone	Ladinian
										"Flagstones"								Quaco congl.	Annapolis fm.	
																		Lower Red sandstone		
														Whitehorse member	Whitehorse member	Gray sandstones, siltstones, shales, etc.				Anisian
								Toad formation	Toad formation	Toad formation										
														Siltstones and sandstones	Spray River / Sulphur Mountain member					
								Grayling formation	Grayling formation											
	?	Ferguson group (Late Paleozoic)	?	Permian	?	Milford (Late Paleozoic)	Saanan group	Permian		?	Permian	?	?	Rundle (Miss.)	Rocky Mountain (Penn.)	Paleozoic	?	Paleozoic Pre-Cambrian	Paleozoic Pre-Cambrian	Underlying beds
	42	18, 70	31, 34	27, 32, 36, 48, 115	12	16	87	76, 77, 92, 109, 111, 126		56, 107	104, 108, 111, 128	1	113	67, 81	123	3, 124a	79	114	114	References to bibliography

Upper / Middle / Lower — TRIASSIC

SURVEY AND GEOLOGY BY BRONSON STRINGHAM,
JAMES F. SYLVESTER AND ALLEN O TAYLOR
1947 — 1949

0 100 200 400 600
SCALE IN FEET

EXPLANATION

Al — ALLUVIUM AND MINE FILL

BINGHAM QUARTZITE (PENNSYLVANIAN)

Q — QUARTZITE AND IMPURE QUARTZITE (dolomitic and limy). Medium grained, occasionally arkosic. Color white, gray and brown. Impure beds slightly greenish near granite due to presence of actinolite, chlorite and diopside.

Ls — LIMESTONE (dolomitic and sandy). Dense and gray to light blue. Beds may lense rapidly. Colored greenish to brown near granite due to presence of diopside, actinolite, chlorite, and andradite.

Fn — FELDSPAR NETWORK IN SEDIMENTS (outer boundary approximate). Microscopic feature: orthoclase and some oligoclase introduced between quartzite grain boundaries forming network appearance.

GrQ — GRANITIZED QUARTZITE. Fine grained, grayish with small white chalky patches and occasional brownish spots. Composed of microscopic quartz, orthoclase, oligoclase, and biotite. Frequent quartzite skiaiths (inclusions).

INTRUSIVE or GRANITIZED

Gr — GRANITE. In small part syenite, quartz monzonite, monzonite, granodiorite, quartz diorite, etc. Texture chiefly granitoid but sometimes fine grained or porphyritic with pink orthoclase crystals. Color gray to dark gray. Biotite always present. Orthoclase, oligoclase and quartz rarely determinable in field.

As — ACTINOLITE SYENITE. A greenish gray medium granitoid rock containing orthoclase, oligoclase, biotite, and interstitial actinolite with frequent irregularly shaped solid patches of actinolite, diopside, and epidote. Interstitial diopside and epidote are occasionally present.

INTRUSIVE

Gp — GRANITE PORPHYRY. In part quartz monzonite porphyry. Phenocrysts constituting 10% to 80% of rock are pink to white orthoclase, oligoclase (often altered) and a little fresh biotite in a green to brown groundmass.

Bl — BIOTITE-QUARTZ LATITE PORPHYRY. Phenocrysts constituting 30% to 50%, are white altered oligoclase and a little fresh biotite which often shows alignment in a greenish groundmass.

HYDROTHERMAL ALTERATION

STAGE I. KAOLINITE—ILLITE. Boundary determined by thin section. This alteration is thoroughly disseminated and does not follow channels. Kaolinite and illite, observable only through the microscope, are always mixed and have developed mostly from feldspar.

STAGE II. HYDROTHERMAL BIOTITE—SERICITE (outer boundary approximate). Fine grained hydrothermal biotite has developed chiefly from primary biotite and feldspar and is recognizable in the field. Microscopic sericite present only in the feldspars. Disseminated type of distribution.

STAGE III. CHLORITE — HYDROTHERMAL BIOTITE. Dark green to black, very dense appearing rock, occurring in streaks within granite. Microscopic chlorite and hydrothermal biotite are very fine grained and intimately mixed.

STAGE IV. QUARTZ — SERICITE. Light (in granite) or dark (in granite porphyry) streaks of quartz and sericite. Most rocks have been affected to some degree but within mapped areas more than 15% of the rocks has been altered.

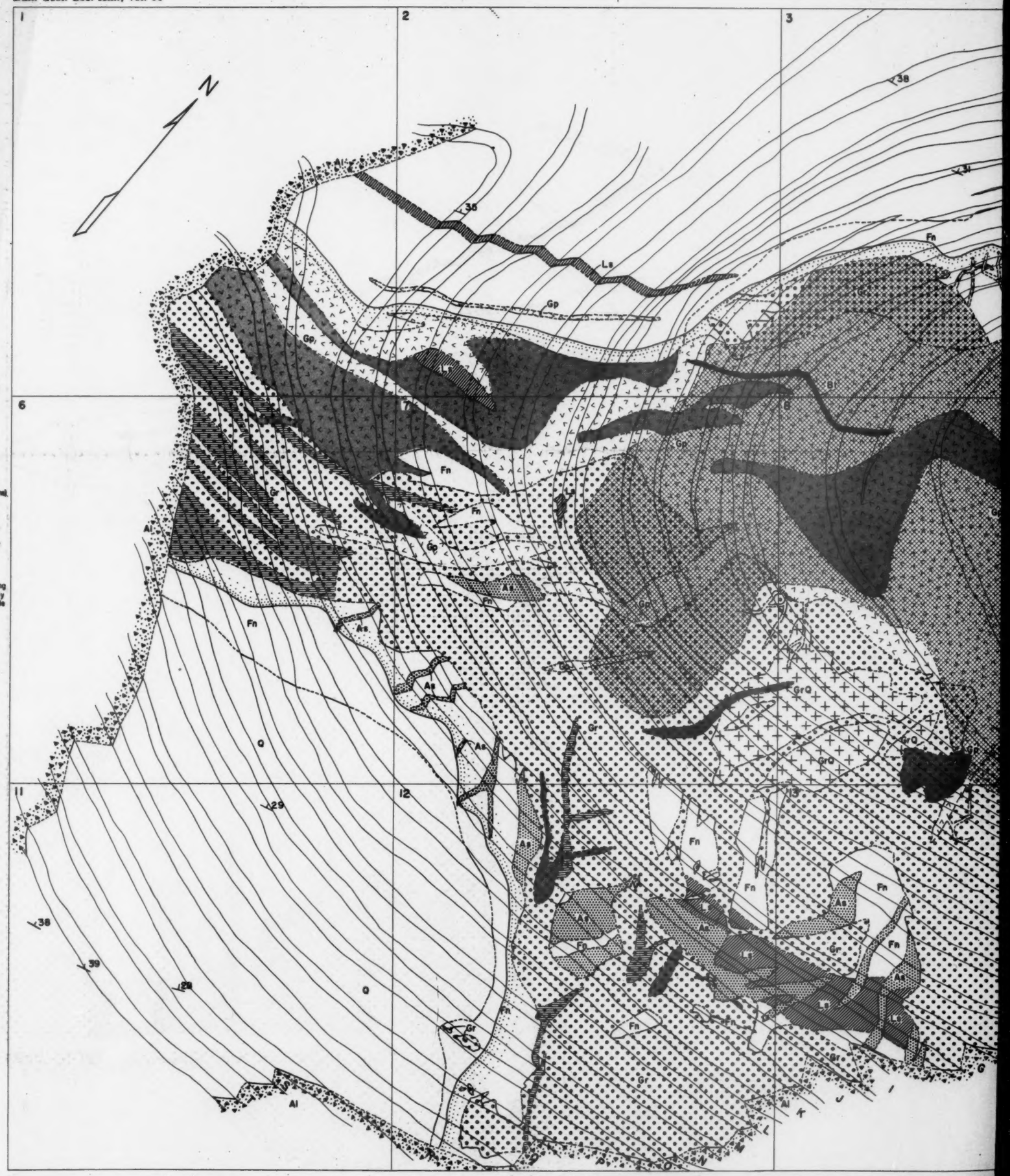
STAGES V, VI, & VII NOT MAPPED (SEE TEXT).

LEVELS AND BANKS. Contacts on banks solid lines. Interpolated contacts on levels dashed lines.

25 — STRIKE AND DIP.

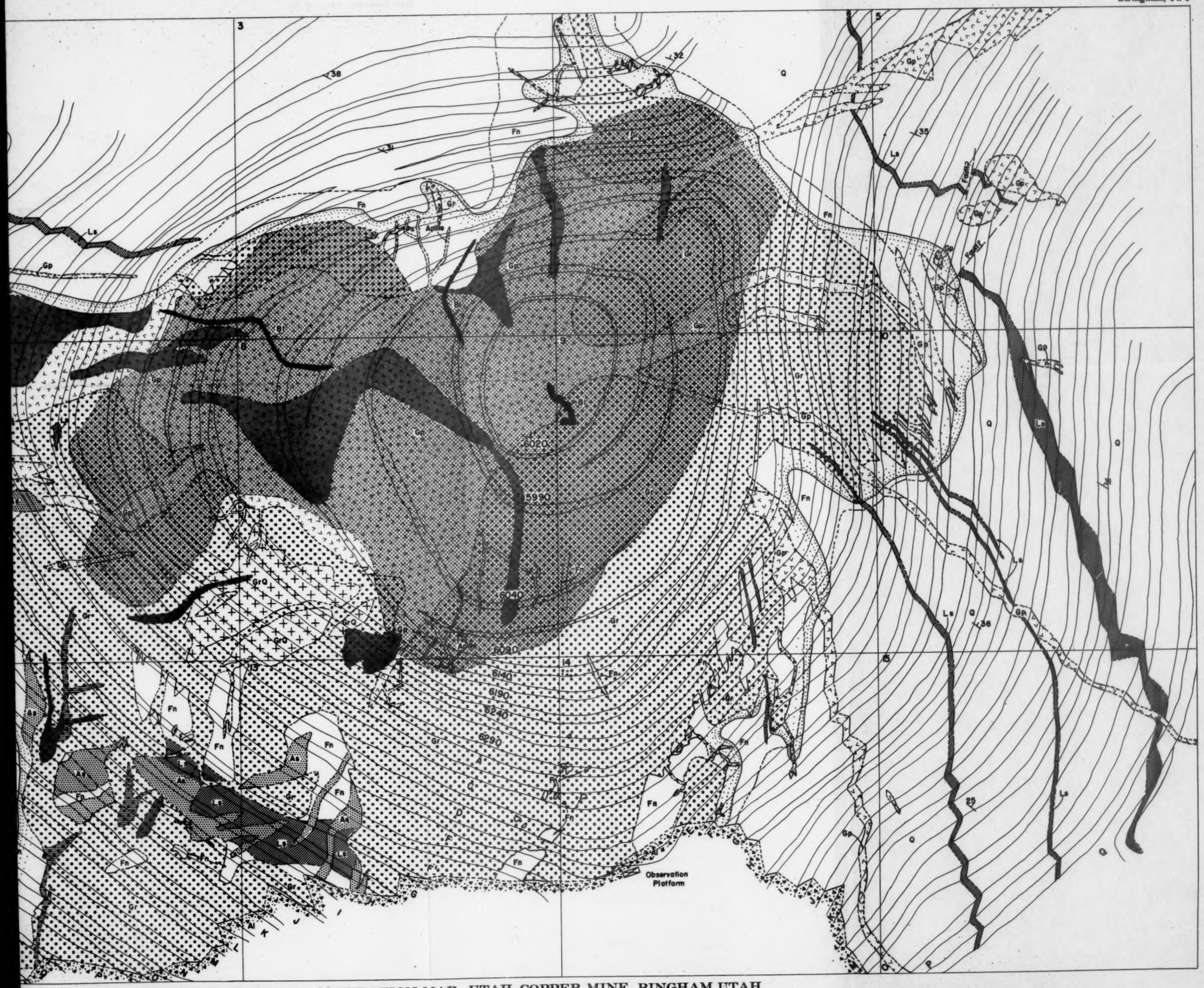
A, B, ... — LEVEL DESIGNATION.

6040 — LEVEL ELEVATION.



GEOLOGIC AND HYDROTHERMAL ALTERATION M

DET-PUB-LIB



GEOLOGIC AND HYDROTHERMAL ALTERATION MAP, UTAH COPPER MINE, BINGHAM UTAH